TELLUS INSTITUTE
for Resource and Environmental Strategies

ECONOMIC ANALYSIS OF WASTE MINIMIZATION ALTERNATIVES TO HAZARDOUS WASTE COMBUSTION

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SUBMITTED TO INDUSTRIAL ECONOMICS, INC.,
IN SUPPORT OF THE REGULATORY IMPACT ANALYSIS
FOR US EPA'S PROPOSED REVISED STANDARDS FOR
HAZARDOUS WASTE COMBUSTORS

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1. Introduction

EPA has proposed revised standards for hazardous waste combustors, including incinerators, cement kilns, and lightweight aggregate kilns, under the combined authority of RCRA and the Clean Air Act. The revised standards will provide greater protection for human health and the environment by limiting emissions of toxic metals, halogenated compounds, particulate matter, and other pollutants. The rule-making process also is also an important opportunity to encourage waste minimization—which includes source reduction, in-process recycling, and out-of-process recycling—as an environmentally preferable alternative to hazardous waste combustion. To explicitly encourage waste minimization, EPA proposes offering a one year extension to facilities with on-site incinerators that need extra time to implement waste minimization projects.

Most importantly, EPA expects the revised standards to shift market incentives toward greater waste minimization. Because of the predicted cost of compliance for the regulated community, EPA expects that the price hazardous waste combustors charge their customers may rise once the rule is promulgated. Such a price increase would increase the economic viability of waste minimization alternatives relative to combustion. EPA considers this an important factor to analyze, because it will help mitigate the adverse economic impacts of the rule on hazardous waste generators, limit the price increase that hazardous waste combustors will be able to pass through to their customers, and lead to greater net environmental and human health benefits.

1.1 Purpose and general approach

EPA must conduct a Regulatory Impact Analysis (RIA) prior to promulgating a final rule, to evaluate the impact the rule will have on human health, the environment, environmental justice, the regulated community, and other interested parties. This analysis will inform the RIA with regard to waste minimization alternatives to combustion. Undertaken by Tellus Institute, this analysis predicts the quantity of waste currently combusted that could be economically diverted from combustion to waste minimization under various hazardous waste combustion pricing scenarios. Because a separate, concurrent analysis developed combustion pricing scenarios, this analysis could not predict an absolute quantity of diverted waste. Instead, our primary product is a substitution demand curve that relates the quantity of waste minimization demanded to the price of hazardous waste combustion. Any combustion pricing scenario may then be combined with this demand curve to formulate a prediction of how much waste will be diverted to waste minimization, which in turn will inform the predicted demand for combustion services.

Our overall approach was deductive, using data on waste and technologies to build a model of the waste minimization business decision on the part of the generating facility. The power of this approach stems from its ability to model a post-promulgation future that is economically different from the past and present. The deductive approach is also simple to understand because it follows the logic that individual facilities might use in making decisions. It is easy to modify because once the model is constructed, new data can be input to provide modified results. The weakness of the deductive approach is that there may be confounding factors, not incorporated into the model, that render the conclusions systematically biased. We discuss some potentially confounding factors in Section 4.

We utilized an inductive approach to analyze one important component of waste minimization—source reduction through process redesign, product redesign, or input substitution—because there are too many variables involved to usefully model such site- and process-specific improvements. Instead, we used historical quantitative data on source reduction at a small sample of facilities to gain a rough picture of what has been possible in the past, then used some simplifying assumptions (informed anecdotally by a number of generating facilities) to generate an estimate of future source reduction. Using this inductive approach, we were able to include the effects of all types of source reduction projects, without having to identify and model them individually. The weakness of this approach is that the future may be different from the past. For instance, the best source reduction opportunities may already have been exhausted, in which case the inductive method will overestimate future source reduction potential. In our analysis, we attempt to qualitatively account for this bias.

1.2 Major Findings

Section 3, Results, offers a detailed presentation of the analysis results. This section provides a brief overview of the most salient results.

- SIC class 28, chemicals and allied products, generated the great majority (64%) of combusted hazardous waste in 1993. SIC 28 facilities work with large quantities of organic chemicals as inputs, solvents, products, byproducts, and cleaning agents, so it is not surprising that they top the list.

- We estimated that 508,534 tons of currently combusted waste will be eliminated by source reduction over the next ten to fifteen years, regardless of combustion prices.

- We developed a substitution demand curve (shown in Figure 5, on page 27) that relates the price of combustion to the quantity of waste minimization (not including source reduction) demanded at that combustion price. However, this curve should be used to predict the change in waste minimization demanded as combustion prices change, rather than to predict the total quantity of waste minimization demanded at a particular combustion price.

- There are a variety of complicating factors that could not be accounted for within the analysis. These include data quality issues, necessary assumptions, and imperfections within individual firms, the economy, and the regulatory system.

2. Methodology

A model of the waste minimization decision at individual facilities and their macro-level effects on the hazardous waste combustion market requires three basic inputs:

- a characterization of the wastes currently being combusted, particularly with regard to their sources
- characterizations of available waste minimization technologies, including both cost profile and waste stream applicability
- a model decision framework

For waste characterization, we selected the RCRA Biennial Reporting System (BRS), the only national database that comprehensively tracks combusted hazardous wastes. For technology characterization, we solicited information from waste minimization technology vendors and consultants. For a decision framework, we employed Total Cost Assessment (TCA), a method that Tellus developed for evaluating investments—particularly pollution prevention investments.

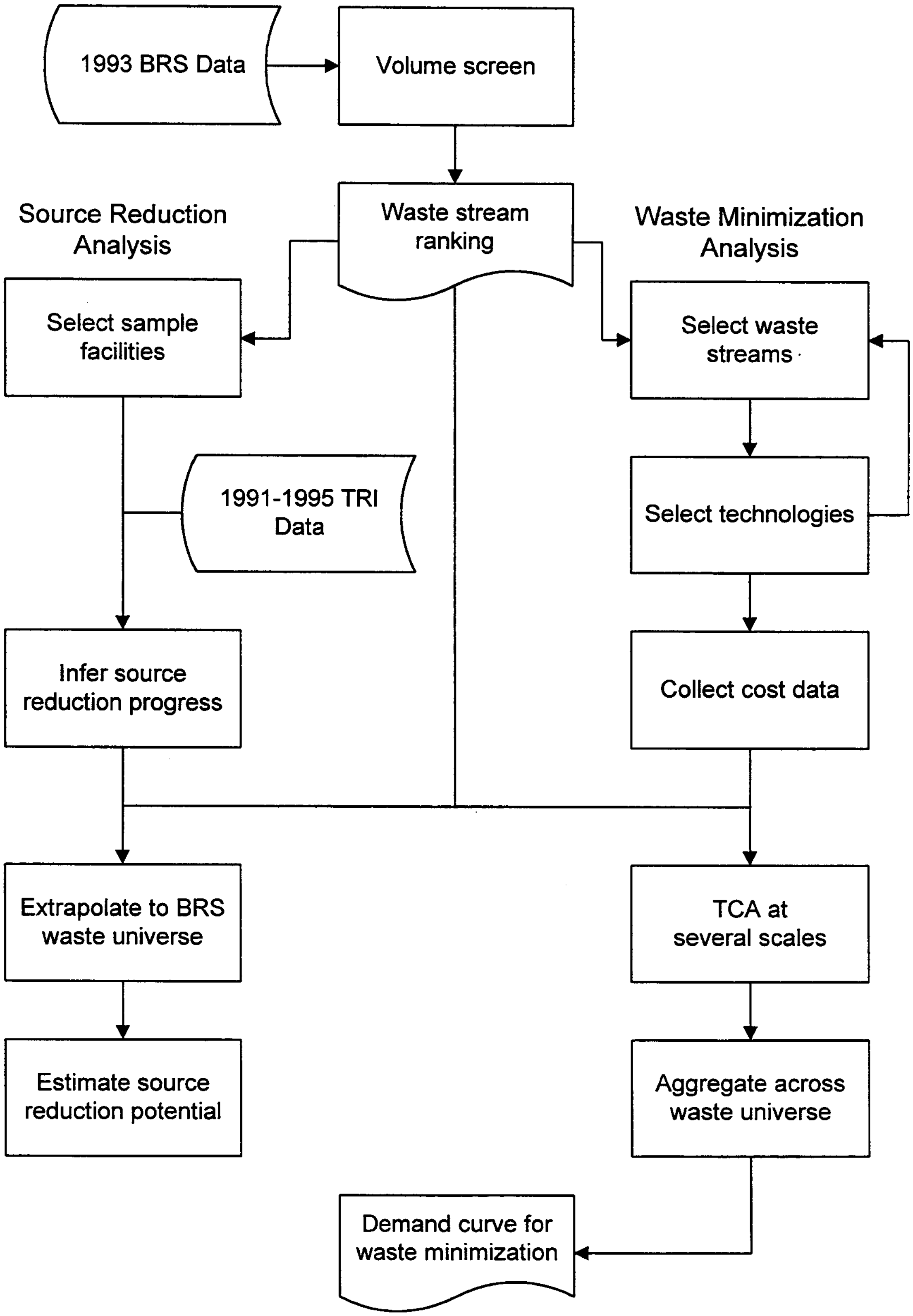
Using BRS data, we developed a profile of where and how combusted hazardous wastes are generated, and we identified the dominant waste categories. We then identified the technologies most applicable to these waste categories, and gathered capital and operating cost information. TCA enabled us to estimate the profitability of each technology at different scales. We applied these estimates to the BRS data to develop a substitution demand curve that relates the price of combustion to the demand for waste minimization.

Lacking a workable, well-defined characterization of source reduction opportunities, we were unable to analyze source reduction opportunities (process redesign, product redesign, and input substitution) in the same manner as waste minimization technologies. Source reduction is closely tied to the specifics of the process, so it is not possible to make defensible generalizations across facilities or industries with enough detail to use TCA. In addition, there are too many different opportunities for source reduction to analyze cost effectively even if it were possible to make generalizations across facilities or industries. Instead, we elected to develop an alternative approach that uses Toxics Release Inventory (TRI) data to infer source reduction achievements at a sample of progressive New Jersey facilities, and then extrapolate to an estimate of future source reduction potential across the nation.

Finally, combining the substitution demand curves for the various waste minimization technologies, we constructed an aggregate substitution demand curve for waste minimization (not including source reduction) for the entire hazardous waste combustion market. This, in turn, can be incorporated into the market model for predicting the impact of the proposed regulatory changes.

Our methodology is presented graphically in Figure 1.

Figure 1: Methodology flow chart



2.1 Waste stream analysis

The objective of the waste stream analysis was to identify the waste streams most amenable to waste minimization and likely to have the greatest effect (in terms of price and quantity changes) on the hazardous waste combustion market.

The 1993 BRS was the most recent major data source available on the generation and management of combusted hazardous wastes.[1] Facilities that generate and receive RCRA hazardous wastes must submit BRS reports in odd-numbered years to EPA on the origin, quantity, type, and destination of each regulated waste. In some states, facilities report both BRS and state-specific data directly to the state environmental agency; the state agency then forwards the relevant information to EPA. The BRS database becomes available to the public roughly two years after the close of the reporting year.

BRS contains Form GM data on waste generation and management by large quantity generators, and Form WR data on waste received by treatment, storage, and disposal (TSD) facilities. On Form GM, the quantity of each waste is listed with a 4-digit SIC code, source code (identifying the industrial process that generated the waste), form code (identifying the physical state and chemical composition of the waste), destination facility ID (for wastes transferred off site) and system code (identifying the waste management system used to treat or dispose of the waste). Form WR lists the source facility ID, form code, and system code.

There are a variety of inherent limitations and data quality lapses that make BRS troublesome to work with. The most serious issues are listed briefly here; all are covered in detail in Appendix A. We developed methods for resolving these various problems, primarily by making simplifying assumptions.

- Form WR, which lists wastes received by TSD facilities, is the only record of wastes generated by small quantity generators (SQGs). Because Form WR lists neither the SIC code of the generating facility nor the source code of the waste, SQG wastes are not well characterized by BRS.

- Many Form GM records lack valid SIC codes, source codes, or form codes.

- Combustion system codes are reported on some Form GM and Form WR reports for destination facilities not permitted to combust hazardous waste.

- Fuel blenders—facilities that blend hazardous waste with virgin fuels—both receive and generate waste. Because fuel blenders do not submit Form WR for virgin fuel inputs, and because they often are vertically integrated with recycling facilities or send much of their waste to recycling facilities, it is not possible to identify which wastes sent to fuel blenders are eventually combusted.

- Many generators reported sending more waste to particular TSD facilities than the TSD facilities reported receiving from the particular generators. As a whole, generating facilities reported sending 8,244,000 tons of hazardous waste to combustion facilities (including fuel blenders) on Form GM, while these same combustion facili-

[1] 1995 BRS preliminary data became available toward the end of the project, but the resources necessary to update the analysis using the new data were not available within the Work Assignment guidelines. Furthermore, the preliminary data remained unverified by some states.

ties reported receiving only 3,765,000 tons on Form WR.[2] Most of the discrepancy is probably the result of both reporting errors on the part of generators and data entry errors or quality control oversights on the part of EPA.[3]

After resolving these problems, we aggregated the individual BRS records—each of which describes a single waste at a single facility—into grouped waste streams based SIC, source, and form codes. Then, we evaluated the waste streams according to the following criteria:

- Volume

  Measured in tons, volume is the most important screen for economically significant waste streams.

- Combustibility

  Waste streams that are more expensive to combust (those with low heat content, high contaminant content, or high solids content) offer greater savings for avoiding combustion.

- Number of facilities

  A large waste stream that is generated entirely or almost entirely by a single facility may be the result of a unique process or other unique situation that precludes analysis in general terms.

- Readiness for waste minimization

  Finally, we selected waste streams for which waste minimization technologies are available.

We applied the volume criterion formally, by ranking the waste streams in descending order. We used the other criteria as an informal guide in selecting waste streams. For each of the high volume waste streams, we attempted to identify applicable waste minimization technologies, while taking into account the combustibility and number of facilities criteria. The results of the waste stream analysis are presented in Section 3.1. A detailed account of the data manipulations necessary to produce a ranking of combusted waste streams is presented in Appendix A.

2.2 Financial analysis of waste minimization technologies

We selected waste minimization technologies concurrently with the waste stream selection process. In other words, we chose technologies that applied to the highest volume waste

[2] After adjustments to account for other data issues.

[3] For example, we directly contacted a generating facility whose GM file reported that two waste streams, totaling over 1.7 million tons, were sent to a combustor that did not report receiving them on Form WR. The environmental manager explained that these waste streams were actually deep-well injected on site. Upon reviewing the BRS reporting forms from 1993, the environmental manager found that the facility had reported these two waste streams correctly, and that EPA had erred when keying in the data. This error represented more than 30% of the discrepancy between Form GM and Form WR combusted wastes, and several other facilities accounted for most of the rest of the discrepancy. However, only a small minority of facilities reported sending exactly as much waste to combustors as combustors reported receiving from them.

streams, and we chose waste streams that were both high volume and amenable to waste minimization. Our decisions were arrived at after many iterations, using both professional engineering judgment and discussions with waste generators, waste management vendors, and waste minimization technology vendors.

Once we had selected waste minimization technologies to analyze, we contacted waste minimization technology vendors to obtain cost information. Specifically, we asked for an estimate of capital costs, operating and maintenance costs (including labor, utilities, and materials), and maximum capacity for each technology at various price points. In general, technology vendors found it difficult to provide detailed cost information, because they prefer to provide highly customized systems depending on the customer's specific waste streams (defined in greater detail than is available in BRS) and site characteristics. However, by inventing sample scenarios with detailed waste stream and site detail, we were able to elicit sufficient cost information for the analysis.

We used Total Cost Assessment (TCA) as our model of how businesses might make capital investment decisions.[4] TCA involves four basic elements:

- an inventory of costs, savings, and revenues, including indirect, less tangible items typically omitted from project analysis, such as compliance, training, testing, liability, product, and corporate image
- costs and savings that are directly allocated to specific process and product lines instead of being pooled in overhead accounts
- time horizons for calculating profitability extended to capture longer term benefits over the useful lifetime of the investment
- profitability indicators capable of incorporating the time value of money and long-term costs and savings

Starting from a generic cost and savings inventory that we developed for earlier TCA projects, we narrowed the list down to the costs and savings that we expected to have a significant impact on the profitability of waste minimization investments. These include the following:

- Capital purchase cost
- Direct labor and supervision (fully burdened), materials (including purchasing department overhead), and utilities to operate and maintain the equipment
- Additional installation costs, such as construction, permitting, engineering, and related equipment
- The value (positive or negative) of residual waste streams, in terms of resale value; reduced disposal cost; or labor and supervision, materials, and utilities avoided through reuse

[4] TCA was originally developed with partial funding from EPA's Environmental Accounting Project. See Allen White, Monica Becker, and James Goldstein. 1992. *Total Cost Assessment: Accelerating industrial pollution prevention through innovative financial analysis, with applications to the pulp and paper industry.* Report to US EPA.

Vendors were typically able to provide capital cost information, as well as estimates of unburdened labor, materials purchase price, and approximate utilities cost information lumped into a single figure for operations and maintenance (O&M) costs. We applied a 50% additional charge to represent supervisory labor, labor overhead, and materials overhead, and to compensate for equipment vendor optimism. For additional installation costs, we developed tailored assumptions for each individual technology, based on professional engineering judgment. These ranged from 0% to 100% of capital costs.

For all technologies, we assumed an average of 80% reduction in waste volume combusted. In some cases, this implies that 80% of the waste stream is separated as a nonhazardous waste (such as wastewater or an organic waste eligible for the proposed comparable fuels exemption) that can be disposed of at little or no cost. In other cases 80% of the waste stream may be purified enough to be sold or reused in place of virgin materials, producing a revenue. In some cases, the 80% may require further processing, at relatively high cost prior to disposal. In a few cases, the 80% may represent waste that is never created due to source reduction—this creates a revenue relative to the status quo by reducing the purchase of virgin materials. Rather than analyze these cases individually for each waste stream, we assumed that on average, the 80% portion poses no costs and provides no revenues. This strikes a balance between wastes that require further expensive processing and reusable chemicals that replace expensive virgin inputs.

We assumed a fifteen year lifetime for all types of capital equipment. Accordingly, we used fifteen years as the time horizon for the analysis. The best indicator of project financial performance is the after-tax net present value (NPV), which we calculated using a typical real discount rate of 12%. We calculated NPV, and then annualized it over the fifteen year time horizon to find the annualized net present cost (NPC).[5] Annualized NPC per ton can be directly compared to after-tax combustion prices.

We took into account the fact that different facilities generate different sized waste streams. Facilities with higher volume streams will experience lower costs per ton, and will be more likely to invest in on-site waste minimization equipment. For smaller generators, waste management vendors may offer a fee for service option that costs less than on-site installation. For off-site vendor installations, we calculated annualized NPC for the versions of selected technologies operating with the lowest cost per ton, then applied a 100% markup to reflect corporate overhead and normal profit on the part of the vendor, as well as transportation and potential liability costs that the generator must bear. This off-site vendor price served as a backstop above which we did not analyze on-site installations.

For each individual facility, if the price of combustion rises above its calculated annualized NPC of waste minimization, waste minimization will become the more cost-effective option. Appendix B demonstrates a sample analysis of an individual facility. Once we had calculated the annualized NPC for each eligible facility, we were able to compare the effective price of waste minimization to the effective price of combustion. Based on the decisions of individual facilities, we constructed a substitution demand curve for each waste minimization technology that shows graphically how many tons of waste will be diverted to waste minimization under different combustion pricing scenarios. The curve incorporates the decision of each individual facility whether to invest in waste minimization. As combustion prices rise, more facilities switch to waste minimization and more waste is diverted from combustion.

[5] NPC = -NPV.

Summing these curves horizontally (with modifications to account for waste streams that could be managed by more than one technology) produced a curve that represents the market for all the waste minimization technologies we analyzed.

2.3 Analysis of source reduction potential

Source reduction proved too difficult to analyze using TCA. Most source reduction opportunities are sensitive to site- and process-specific parameters. Particularly in the chemicals industry, source reduction opportunities will usually depend on the specific chemical reactions, the specific product quality standards, and the specific processes and process equipment involved. Often substantial research and development must precede implementation to ensure that process changes will have the desired effect. In other cases, a simple and inexpensive change, such as changing the production schedule, may reap significant savings. Furthermore, most source reduction occurs not with the primary purpose of reducing pollution, but as a result of new equipment purchases and periodic process optimizations that routinely occur in chemical plant operations. It is impossible to broadly predict specific source reduction opportunities without detailed knowledge of individual facilities.

Instead, we developed a prediction of source reduction potential based on recent experience at a group of chemical facilities in New Jersey that have proactive pollution prevention programs. New Jersey is a fertile arena for studying source reduction, because state pollution prevention planning and chemical use reporting requirements provide strong incentives for source reduction. We developed a measure of source reduction progress based on Toxics Release Inventory (TRI) data from 1991 to 1995 at a sample of New Jersey facilities in SIC 28 with significant combusted waste streams. TRI includes an index of production activity and a measure of the quantity of chemicals prior to recycling or treatment. Using these data, we calculated the percent reduction in chemicals prior to recycling or treatment per unit of production activity at each facility. This screened out the effects of out-of-process recycling and changes in production levels, to provide an effective measure of source reduction progress.

We started with a list of 61 chemical facilities in New Jersey that generated more than 100 tons of combusted waste. Of these, thirteen reported qualitative source reduction methods. We also examined the six largest facilities, even though they had not reported qualitative pollution prevention.

Because TRI measures quantities of particular chemicals, we needed to make several assumptions to translate source reduction progress into reduced quantities of combusted waste. First, on a facility by facility basis, we matched TRI chemicals to BRS waste streams, based on professional judgment. Then we made the simple assumption that the reduction in combusted waste was proportional to the reduction in hazardous constituents. Using 1993 as a base year, we calculated the average percent reduction in combusted waste from 1991 to 1995.

Of the nineteen facilities (thirteen small and six large), we were able to match TRI and BRS wastes at twelve. Of these twelve, we found that seven had achieved substantial source reduction. These seven facilities include both large and small facilities, from three 4-digit SIC codes within SIC 28. In terms of waste volume and SIC code distribution, these seven facilities approximate the mix of SIC 28 facilities nationwide with combusted waste streams.

Next, we assumed that New Jersey chemical facilities in general are more proactive with source reduction due to pressure from the state's materials accounting and pollution prevention planning requirements. Further, we assumed that our selected sample of facilities that have demonstrated source reduction progress based on TRI data are particularly proactive. We then estimated that the U.S. chemical industry as a whole can expect to achieve at least a similar rate of source reduction over the next 5–10 years as more facilities start pollution prevention planning programs and adopt materials accounting techniques—driven by government mandates, public pressure for better environmental performance, or simply internal resource efficiency and process optimization objectives.

We do not expect the rate of source reduction to be sensitive to changes in combustion prices. Other benefits, such as improved yields from reduced waste, decreased downtime from reduced buildup of contaminants, improved quality, or improved environmental image are usually more important than avoided disposal costs in justifying source reduction projects.[6] Some of the best opportunities for source reduction often occur when facilities replace outdated process equipment with new technology that provides superior performance in many areas, including but not limited to pollution prevention. Tellus has worked with a wide variety of facilities on analyzing source reduction projects using TCA, and we have found that it is rarely the avoided cost of waste disposal that tips the balance in favor of source reduction. Research by Charles Rooney shows that disposal costs (including internal waste handling costs) constitute about 13% of the total cost of waste at eighteen chemical plants, while raw materials and value-added labor constitute 87%.[7] In this milieu, a 100% increase in combustion prices will have less effect on source reduction than a 20% increase in raw materials prices.

[6] The out-of-process technologies described in Section 3.2.1 do not typically provide these benefits because, unlike upstream source reduction, they generally do not directly affect the production process.

[7] Rooney, Charles. 1993. Economics of pollution prevention: How waste reduction pays. *Pollution Prevention Review* (Summer) 3(3):261–276.

3. RESULTS

The results are presented in three sections. Section 3.1 displays the highest volume combusted waste streams, and discusses the priority waste streams that we chose to analyze. Section 3.2 describes the twelve waste minimization technologies, and presents the financial analysis of each. Section 3.3 details our estimate of source reduction potential, and Section 3.4 shows how we derived the overall demand curve for waste minimization.

3.1 Waste streams

Table 1 presents the results of the waste stream analysis volume screen. It lists the highest volume waste streams, where "waste stream" is defined as a unique combination of 2-digit SIC class, source code, and form code.

SIC 28, chemicals and allied industries, dominates the list—in fact, SIC 28 was responsible for 64.0% of all combusted wastes. SIC 2869, industrial organic chemicals not elsewhere classified, was the largest 4-digit SIC code within SIC 28, accounting for 23.7% of all combusted wastes. The major division within SIC 28 in terms of waste minimization opportunities is between continuous process bulk chemical manufacturers and batch process specialty chemical manufacturers. However, this division is not reflected in the 4-digit SIC codes—particularly because SIC 2869, a "not elsewhere classified" group, is so important. Accordingly, we decided to analyze SIC 28 as a group, focusing more on source codes and form codes than 4-digit SIC codes in the technology selection process. We also selected technologies for both continuous and batch processes. Additionally, although we selected technologies specifically for SIC 28, several of the technologies could apply to other SIC classes. We extended the financial analyses to account for these.

Of the eight waste streams on Table 1 that are not from SIC 28 (shaded), four are near the top of the list. The largest has neither SIC, source, nor form information. The second and fourth are from remediation activity, so are less amenable to waste minimization. The third is from SIC 42, trucking and warehousing, which consists of chemical transporters and handlers, rather than producers or generators, and is less amenable to waste minimization. Furthermore, a single facility in Texas is responsible for 99% of the volume, making the waste difficult to analyze without facility-specific information. Of the four smaller streams, three lack SIC codes. We elected not to analyze any of these waste streams individually.

Table 2 presents another view of the wastes from SIC classes other than 28. It lists the highest volume source code and form code combinations remaining once SIC 28 is excluded. The first and third combinations are from remediation activity, while 99% of the second is from the facility in Texas mentioned above. The fourth, other wastewater treatment sludge, could include organic sludges contaminated with a wide variety of metals and other inorganic materials; this would be difficult to analyze. Of the remaining combinations, we decided to focus on oil wastes (waste oil and oil-water emulsion or mixture) and waste paint. Both waste paint and oily wastes are generated by a large number of facilities in a wide variety of industries. Because off-site technologies are available to handle these two types of wastes, we decided to ignore SIC code information when analyzing them.

In summary, our selected waste streams are:

- SIC 28, chemicals and allied industries, which includes a variety of source code and form code combinations (2,017,992 tons)

- Oily wastes, including form codes B205, oil-water emulsion or mixture, B206, waste oil, and B603, oily sludge (175,713 tons)
- Source code A21, painting, matched with form code B209, organic paint, ink, lacquer, or varnish (17,632 tons)

Table 1: Highest volume waste streams

SIC Class		Source Code		Form Code		Facilities	Tons	Percent
28	Chemicals and allied products	A33	Product distillation	B101	Aqueous waste with low solvents	8	230,265	8.52%
28	Chemicals and allied products	A37	Spent process liquids removal	B101	Aqueous waste with low solvents	18	218,191	8.08%
	(Blank)		(Blank)		(Blank)	1,826	166,024	6.14%
28	Chemicals and allied products	A37	Spent process liquids removal	B105	Acidic aqueous waste	8	117,110	4.33%
28	Chemicals and allied products	A33	Product distillation	B219	Other organic liquids (specify)	58	102,301	3.79%
38	Instruments and related products	A63	RCRA Corrective Action at solid waste management unit	B201	Concentrated solvent-water solution	1	93,901	3.48%
42	Trucking and warehousing	A04	Flush rinsing	B219	Other organic liquids (specify)	4	90,073	3.33%
28	Chemicals and allied products	A34	Product solvent extraction	B203	Nonhalogenated solvent	42	87,530	3.24%
87	Engineering and management services	A69	Other remediation	B407	Other halogenated organic solids (specify)	1	78,413	2.90%
28	Chemicals and allied products	A34	Product solvent extraction	B105	Acidic aqueous waste	1	67,194	2.49%
28	Chemicals and allied products	A34	Product solvent extraction	B102	Aqueous waste with low other toxic organics	1	49,077	1.82%
28	Chemicals and allied products	A75	Wastewater treatment	B503	Wastewater treatment sludge with toxic organics	7	43,032	1.59%
28	Chemicals and allied products	A37	Spent process liquids removal	B219	Other organic liquids (specify)	32	40,913	1.51%
28	Chemicals and allied products	A09	Clean out process equipment	B203	Nonhalogenated solvent	182	39,134	1.45%
28	Chemicals and allied products	A35	By-product processing	B101	Aqueous waste with low solvents	9	38,522	1.43%
28	Chemicals and allied products					185	34,429	1.27%
28	Chemicals and allied products	A33	Product distillation	B203	Nonhalogenated solvent	54	33,337	1.23%
28	Chemicals and allied products	A37	Spent process liquids removal	B201	Concentrated solvent-water solution	27	30,488	1.13%
28	Chemicals and allied products	A32	Product filtering	B101	Aqueous waste with low solvents	4	27,780	1.03%
28	Chemicals and allied products	A89	Other pollution control or waste treatment	B601	Still bottoms of halogenated solvents or other organic liquids	1	26,633	0.99%
28	Chemicals and allied products	A37	Spent process liquids removal	B102	Aqueous waste with low other toxic organics	6	25,534	0.95%
28	Chemicals and allied products	A31	Product rinsing	B101	Aqueous waste with low solvents	7	24,498	0.91%
28	Chemicals and allied products	A33	Product distillation	B211	Paint thinner or petroleum distillates	2	22,731	0.84%
28	Chemicals and allied products	A37	Spent process liquids removal	B202	Halogenated solvent	11	22,181	0.82%
28	Chemicals and allied products	A37	Spent process liquids removal	B204	Halogenated/nonhalogenated solvent mixture	30	22,153	0.82%
28	Chemicals and allied products	A31	Product rinsing	B204	Halogenated/nonhalogenated solvent mixture	8	21,637	0.80%
29	Petroleum and coal products	A75	Wastewater treatment	B504	Other wastewater treatment sludge	11	21,094	0.78%
28	Chemicals and allied products	A73	Solvents recovery	B204	Halogenated/nonhalogenated solvent mixture	7	19,618	0.73%
28	Chemicals and allied products	A78	Air pollution control devices	B101	Aqueous waste with low solvents	4	19,533	0.72%
28	Chemicals and allied products	A89	Other pollution control or waste treatment	B701	Inorganic gases	7	17,201	0.64%
28	Chemicals and allied products	A35	By-product processing	B219	Other organic liquids (specify)	28	17,147	0.63%
28	Chemicals and allied products	A33	Product distillation	B602	Still bottoms of nonhalogenated solvents or other organic liquids	26	17,075	0.63%
28	Chemicals and allied products	A49	Other processes other than surface preparation (specify)	B204	Halogenated/nonhalogenated solvent mixture	11	16,894	0.63%
28	Chemicals and allied products	A03	Caustic cleaning	B110	Caustic aqueous waste	11	16,131	0.60%
28	Chemicals and allied products	A35	By-product processing	B207	Concentrated aqueous solution of other organics	14	15,648	0.58%
28	Chemicals and allied products	A37	Spent process liquids removal	B203	Nonhalogenated solvent	87	15,596	0.58%
28	Chemicals and allied products		(Blank)	B204	Halogenated/nonhalogenated solvent mixture	369	15,176	0.56%
	(Blank)		(Blank)	B203	Nonhalogenated solvent	1,608	15,032	0.56%
28	Chemicals and allied products		(Blank)	B203	Nonhalogenated solvent	449	14,664	0.54%
	(Blank)		(Blank)	B204	Halogenated/nonhalogenated solvent mixture	1,147	13,985	0.52%
	(Blank)		(Blank)	B603	Oily sludge	103	12,197	0.45%
						Total	2,000,072	74.04%

Table 2: Source/Form combinations, SIC 28 excluded

Source Code		Form Code		Facilities	Tons	Percent
A63	RCRA Corrective Action at solid waste management unit	B201	Concentrated solvent-water solution	1	93,900	3.48%
A04	Flush rinsing	B219	Other organic liquids (specify)	24	90,298	3.34%
A69	Other remediation	B407	Other halogenated organic solids (specify)	12	79,025	2.92%
A75	Wastewater treatment	B504	Other wastewater treatment sludge	34	21,353	0.79%
A21	Painting	B209	Organic paint, ink, lacquer, or varnish	1,194	17,186	0.64%
A54	Oil changes	B206	Waste oil	885	16,564	0.61%
	(Blank)	B203	Nonhalogenated solvent	1,540	13,876	0.51%
A57	Discarding off-spec material	B205	Oil-water emulsion or mixture	68	12,785	0.47%
A75	Wastewater treatment	B603	Oily sludge	33	12,769	0.47%
A49	Other processes other than surface preparation (specify)	B205	Oil-water emulsion or mixture	26	12,388	0.46%
				Total	370,144	13.69%

3.2 Waste minimization technologies

3.2.1 Technologies

Table 3 presents an overview of the selected waste minimization technologies. The SIC codes, source codes and form codes used on Table 3 are listed in Appendix C.

The first eleven technologies are typically installed post-process. Cleaning in place, the twelfth, is a simple method for source reduction in the batch cleaning process. The technologies fall into three broad categories: separation, contaminant removal, and volume reduction. Separation technologies separate mixed liquids, such as two organic solvents or a solvent mixed with water. Contaminant removal technologies remove dissolved metals, suspended solids, or other contaminants from a liquid. Volume reduction technologies remove water, making the residual more concentrated. All three types promote recycling, because they purify one or more portions of the waste stream. For example, a waste stream consisting of mixed halogenated and nonhalogenated solvents might be separated with enough purity that one or both solvents can be reused.

Separation and volume reduction technologies leave behind a residual that is more concentrated with contaminants. In some cases the concentration may be high enough to recover valuable contaminants, such as metals. But in most cases, the residual will simply be sent to a hazardous waste combustor—typically an incinerator for highly contaminated residual wastes. Incinerators may charge a 100% to 500% premium for such wastes. If the price of combusting the residual rises fivefold (a 400% premium), it will cost just as much to combust our assumed 20% residual as it would have cost to combust the entire waste stream without waste minimization. We assumed that, on average, incinerators will command a 100% premium to combust the residual from separation and volume reduction technologies. We assumed that the residual contaminants from contaminant removal technologies are not combusted, but are recovered or disposed of by other means. We also assumed that, on average, these other means cost the same as combustion plus a 100% premium (because combustion is usually less expensive than other disposal methods).

The technologies are briefly described below.

- Distillation

  Distillation is a thermal process used to separate mixed liquids based on differences in their boiling points. Supplemental distillation steps may be added to a process, either to increase the yield of the primary product or to separate out an additional byproduct. We analyzed three types of distillation. Simple distillation boils off the higher boiling point liquid, leaving behind the lower boiling point liquid and any contaminants. Vacuum distillation lowers the pressure within the distillation apparatus in order to reduce the heat energy required. Fractional distillation uses a fractionating column to achieve a purer distillate.

- Filtration

  Filtration technologies are used to remove contaminants from liquid streams. Multiple filtration steps can achieve a purer filtrate and increase filter life. In some cases additional chemical inputs are necessary to precipitate ions from solution. Microfilters are available to isolate almost any size of suspended particle.

- Reverse Osmosis

  Reverse osmosis is a crossflow filtration technology, based upon the processes of osmosis—diffusion across a semipermeable membrane—and ionic repulsion. Reverse osmosis requires equipment suited to operating under pressure.

- Diffusion Dialysis

  Diffusion dialysis uses semipermeable, ion-selective membranes. Cation membranes allow copper, nickel, aluminum, and other cations to pass, while anion membranes allow chloride, chromates, and other anions to pass. Osmotic pressure drives the separation.

- Electrodialysis

  Electrodialysis uses electrical charges to drive materials across semipermeable membranes similar to those used in diffusion dialysis. Selectively placed anodes and cathodes promote ion movement across the membranes.

- Ion Exchange

  Ion exchange is a technology based upon chemical reactions in which an ion from a solution is exchanged for a similarly charged ion attached to a solid resin. Harmless hydrogen ions may be exchanged for cations (such as many metal species) and hydroxyl ions may be exchanged for anions (such as chloride). Resins are often tailored to capturing specific chemicals. The resin must be periodically regenerated to remove the captured chemicals and replenish the hydrogen or hydroxyl ions. Resin regeneration requires the use of additional chemicals, usually a strong mineral acid or base.

- Pyrohydrolysis

  Pyrolysis is a thermal treatment to destroy or recover a variety of waste constituents. Pyrohydrolysis (or hydropyrolysis) manages aqueous streams by vaporizing off water in a low-oxygen environment. In addition, salts may crystallize and metals may oxidize. With an acidic or alkaline waste, the residual is much more highly concentrated, and can often be reused.

- Oil-Water Separation

  Gravimetric separation relies on the density differential between oil and water. The process is enhanced through various features for turbulence reduction, coalescence, and fraction removal.

- Cleaning in Place

  Cleaning is an aspect of the batch production process that engineering largely ignored until recently. The conventional method for tank washing entails filling the vessel with cleaning solution, agitating the solution, discharging the vessel contents, and repeating the process. Cleaning in place ordinarily consists of a spray ball installed near the top of the vessel, which allows for a small volume of cleaning solution to be used to spray interior vessel surfaces. The waste stream will have smaller volume, but will contain the same amount of the material being cleaned out of the vessel.

Table 3: Selected waste minimization technologies

Technology	Purpose	Off Site	SIC Codes	Source Codes	Form Codes	Quantity Eligible
Simple distillation	Separation	yes	All	A07, A19, A21, A34	B201–204, B207, B209, B211	155,889
Vacuum distillation	Separation	yes	All	A01, A04–07, A09, A19, A21, A31–32, A34–35, A37, A51, A73, A78–79	B101–102, B111–114, B201–204, B207, B211, B219	1,106,704
Fractional distillation	Separation	no	2821, 2833–34, 2865, 2869, 2879, 2899, 2911	A01, A04, A07, A09, A19, A31, A33–35, A37, A73, A79	B101–102, B201–204, B207, B211, B219	1,151,868
Filtration (Micro, Single, or Multiple)	Contaminant removal	yes	All except 4111, 4231, 5541, 7996	All except A32, A51–99	B102, B111–112, B115–116, B119, B205, B207, B219	448,512
Reverse osmosis (Single or Multiple)	Contaminant removal	yes	All	A04–06, A31, A51, A76, A79	B102, B111–112, B115–116, B119, B205, B207, B219	121,803
Diffusion dialysis	Contaminant removal	no	All except 1611, 1622–23, 2652, 3612, 4011, 4225–26, 5043, 5171, 7699, 8062	A01–03, A19, A22–23, A26, A32–35, A37, A73	B103–104, B106–109	3,582
Electrodialysis	Contaminant removal	no	2819, 2834, 2899, 3312, 3354–55, 3441, 3452, 3471, 3479, 3499, 3585, 3672, 3674, 3714, 3721, 3724, 3743, 3764, 3861, 3823	A01–03, A22–24, A26–27	B105, B110–116, B119	975
Ion exchange for Acids	Contaminant removal	no	33, 34, 36, 37, 38, 7384	A02, A22, A26–27	B103–105	903
Ion exchange for Metals	Contaminant removal	yes	33, 34, 36, 37, 38, 7384	A02–04, A06, A09, A22–23, A25–27, A31, A40, A78–79	B110, B112, B114–116, B119	2,253
Pyrohydrolysis	Volume reduction	yes	2869, 2899, 3321, 3355, 3441, 3443, 3471, 3672, 3721, 3724	A01–02, A22, A26–27, A29	B103	761
Oil-water separation	Separation	yes	All except 1611, 4922	A19, A51, A54, A89	B205	7,541
Cleaning in place	Volume reduction	no	2087, 28, 2911	A04, A09, A31, A37	All	121,253

3.2.2 Financial Analyses

We analyzed each technology individually, over the full range of waste streams to which it is applicable, as listed in Table 3. The product of each analysis is a substitution demand curve relating the price of combustion to the demand for the particular waste minimization technology, assuming none of the other technologies are available. These substitution demand curves are shown in descending order by quantity in Figure 2, Figure 3, and Figure 4. The price of combustion is plotted on the vertical axis, and the quantity of waste processed by each technology is plotted on the horizontal axis. By drawing a horizontal line at the expected price of combustion, one could predict the approximate amount of waste that would be diverted to any particular technology as an alternative to combustion. The curves are mutually exclusive; they do not account for the overlapping eligibility of some waste streams.

But it is important to note that at the currently prevailing price of combustion (approximately $70 per ton), this model predicts that some combusted waste streams should already have been diverted to waste minimization technologies, such as fractional distillation, filtration, cleaning in place, and reverse osmosis. Reasons why this has not occurred include data issues, the assumptions we used in the analysis, and real-world barriers to waste minimization. These are discussed in Section 4. Because of these limitations in the model, we recommend using the substitution demand curves to predict *changes* in the demand for waste minimization as combustion prices change, rather than to predict the total quantity of waste minimization demanded at a particular combustion price. Predicting only the change in waste minimization eliminates from consideration facilities that could already have adopted waste minimization economically, but did not. In other words, facilities that did have not adopted waste minimization that is already cost-effective may not adopt cost-effective waste minimization in the future.

Our analysis reveals that three technologies—diffusion dialysis, electrodialysis, and pyrohydrolysis—are not cost-competitive with combustion even if combustion prices rise to $400 per ton. These three technologies are not shown in the figures.

Four technologies—filtration, reverse osmosis, ion exchange for metals, and oil-water separation—appear to be more cost-effective than combustion even at combustion prices as low as $50 per ton. Although, like most other technologies, these four are not competitive at combustion prices approaching zero, within the realistic range of $50 to $400 per ton they are cost-effective even for the smallest facilities. This is in large part due to the predicted availability of off-site vendor services at low cost.

Cleaning in place is unique among the technologies presented here in that it should be cost-effective for many facilities even at a combustion price of $0 per ton. Cleaning in place is a source reduction technique that reduces chemical usage, obviating post-process waste minimization or waste disposal. Eliminating waste, rather than processing it after it is created, saves money by making more efficient use of inputs, even if waste disposal is free.

Simple distillation and ion exchange for acids display some sensitivity to combustion prices. Ion exchange for acids becomes competitive when combustion prices reach $120 per ton; simple distillation becomes competitive when combustion prices reach $200 per ton.

Vacuum distillation, in Figure 2, is the most price sensitive technology. Its substitution demand curve illustrates this well. As combustion prices rise from $80 to $150 per ton, the largest facilities begin to adopt vacuum distillation. Recall that larger facilities can spread costs over a larger volume of waste, achieving lower costs per ton. At $160 per ton, off-site vacuum distillation services catering to small facilities become competitive. We assumed that off-site vendors would offer their services at a price equal to twice the cost of operating the largest on-site facilities.

Cleaning in place and fractional distillation appear to be only slightly sensitive to changes in the price of combustion. This is because the smaller facilities, for whom these technologies do not become cost-effective until combustion prices rise, have only a minor effect on the quantity of waste diverted. These technologies are cost-competitive for large facilities even at very low combustion prices.

Figure 2: Substitution demand curves for individual technologies I

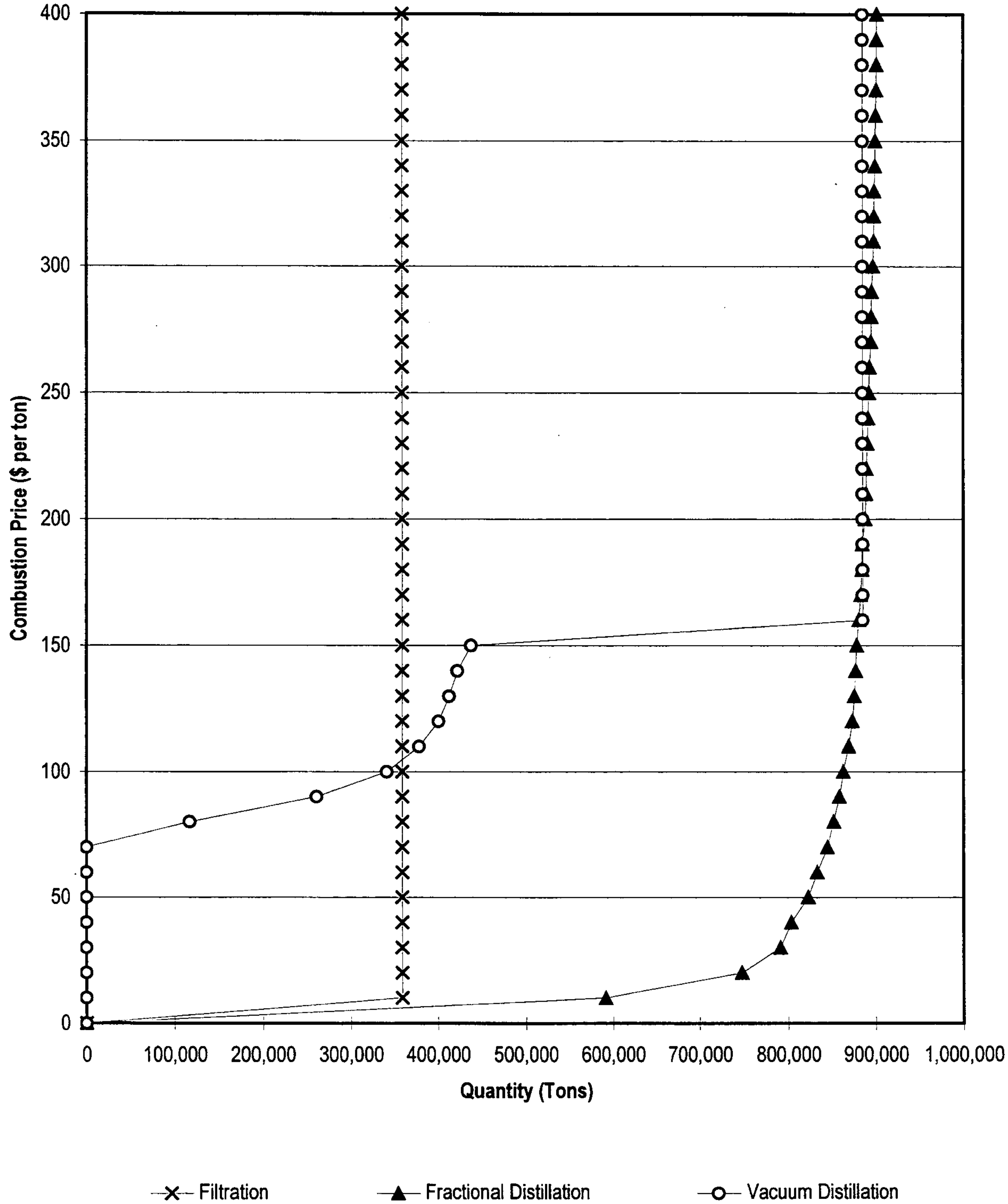


Figure 3: Substitution demand curves for individual technologies II

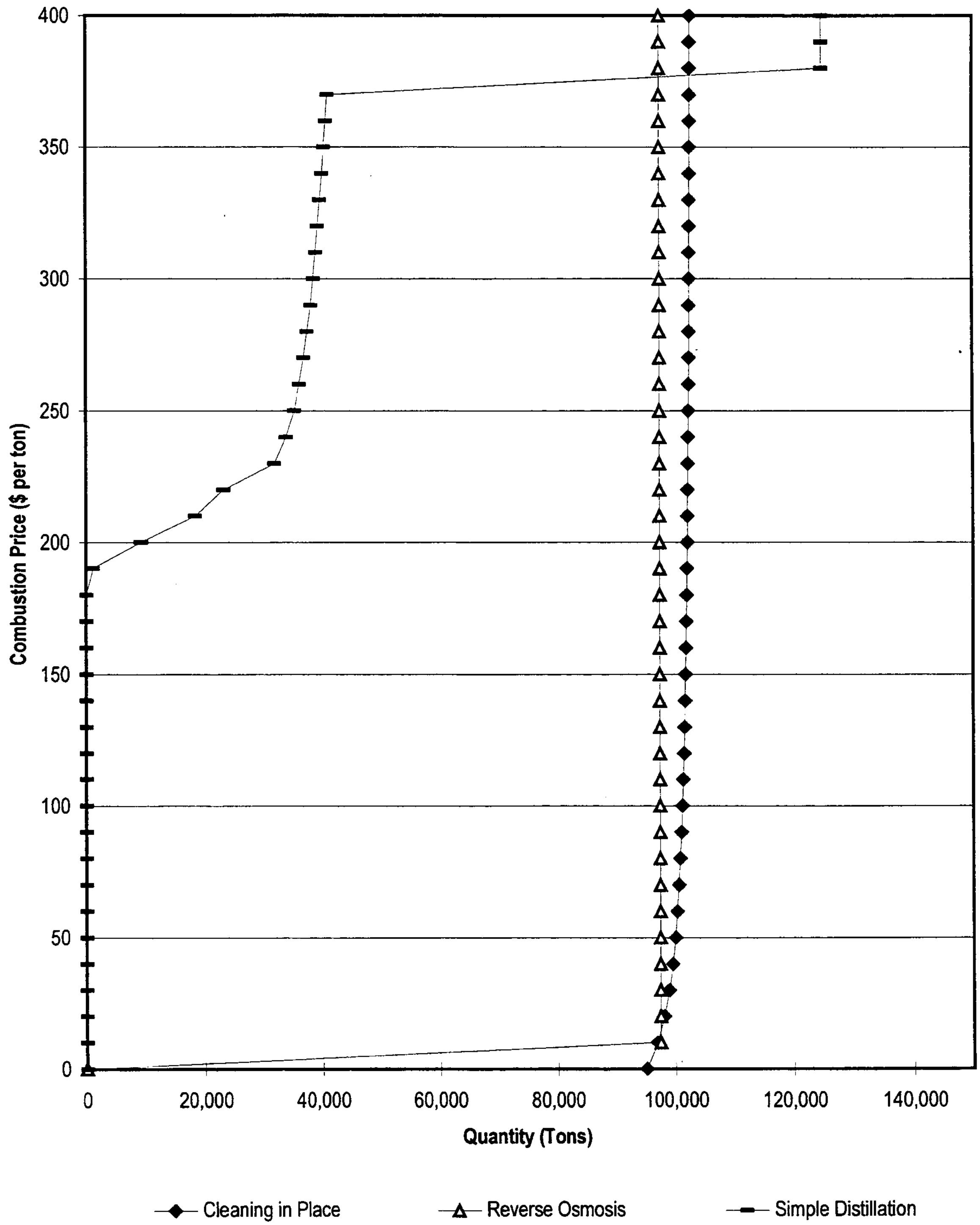
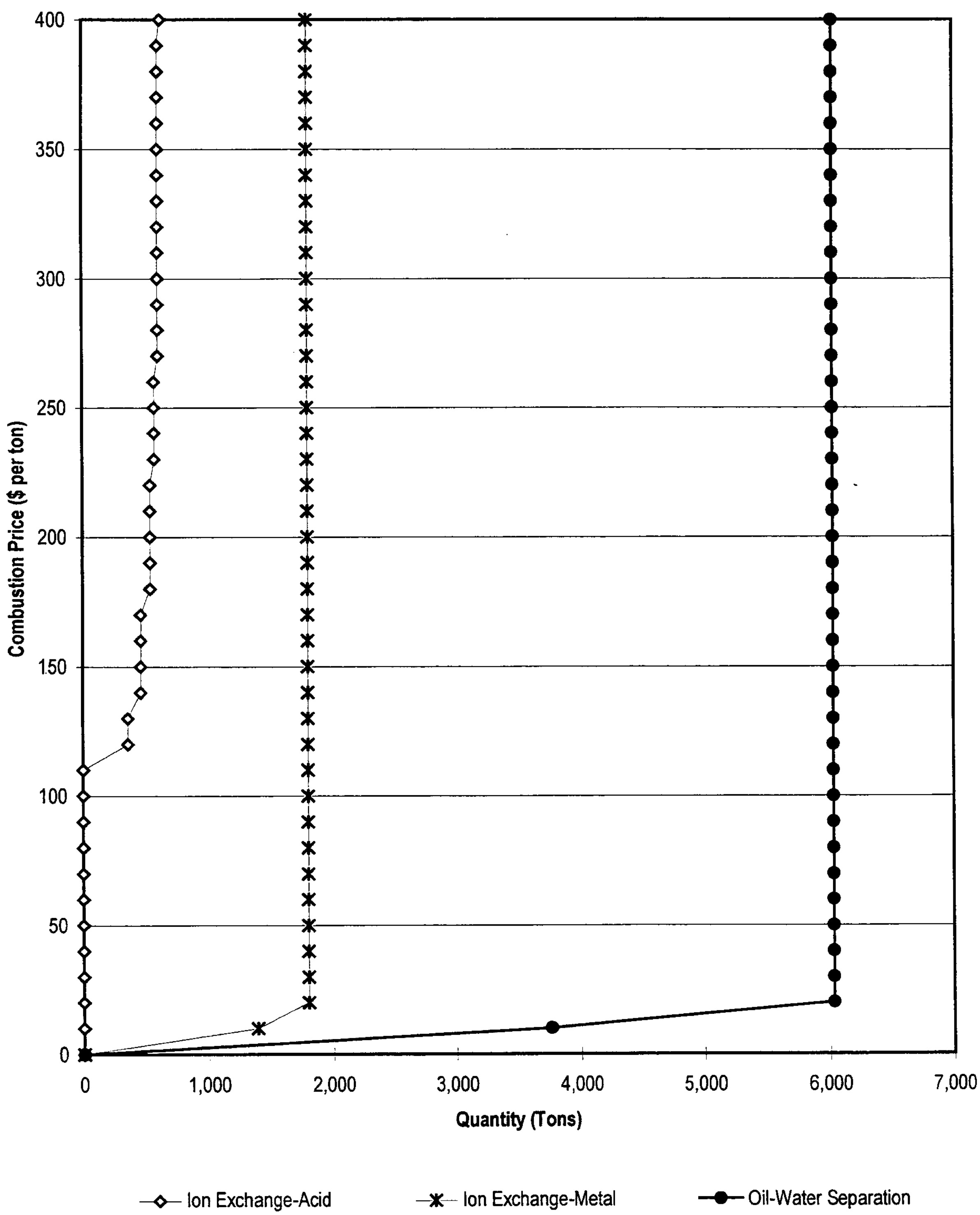


Figure 4: Substitution demand curves for individual technologies III



3.3 Source reduction

From among the 61 New Jersey chemical facilities that generated more than 100 tons of combusted waste, we used TRI data to identify seven facilities that achieved source reduction, defined as a reduction in production-normalized waste prior to recycling or treatment. These seven facilities are shown in Table 4. Total Waste is the total combusted waste (from the 1993 BRS) at the facility. Matched Waste is the combusted waste from the 1993 BRS that we were able to match with TRI chemicals, projected to 1991 and 1995 based on source reduction rates. Reduction is the ratio of the change in Matched Waste to Total Waste. The cumulative estimated source reduction achieved by these facilities from 1991 to 1995, in terms of total 1993 combusted waste volume, is 25.2%.

The Total Waste column illustrates that these facilities represent a broad range of sizes—including both large and small facilities within SIC 2869—and can serve as an approximate cross section of SIC 28 in general. We take their achievements in source reduction as an indication of the further source reduction of combusted wastes that SIC 28 as a whole should be able to achieve over the next decade. Thus, we estimate the potential for at least 25.2% of the total combusted waste in SIC 28 (25.2% * 2,017,992 tons = 508,534 tons) to be "diverted" from combustion to source reduction.

These estimates assume a constant level of production in the chemicals industry. We indexed our analysis to production precisely to exclude the effects of changes in production and to isolate true source reduction. If production in SIC 28 increases, source reduction achievements should increase along with production, but the quantity of waste available for combustion would also increase. That is, waste destined for combustion should increase by 74.8% (100% - 25.2%) of the increase in production.

Although source reduction is not significantly sensitive to the price of combustion, it is important to recognize the effect of source reduction on the combustion market. Source reduction gradually reduces the quantity of waste available for combustion, lowering demand in the combustion market and putting a damper on rising combustion prices. Source reduction is not a competitor to combustion; it is an exogenous influence on the combustion market.

The following source reduction anecdotes, drawn from our previous work in various states, illustrate the wide variety of source reduction opportunities in the chemicals industry, from simple process modifications to far-reaching process upgrades.

- A polypropylene manufacturer modernizes an old facility by using a new type of process. The catalyst in the new process improves efficiency, producing more polypropylene for each pound of propylene used and reducing hydrocarbon wastes. As a result of the waste reduction, the facility closes its industrial furnace hazardous waste combustion unit.

- A polyethylene operation redesigns its reactor quenching process so that ethylene vapors are vented back to upstream processes rather than to the on-site gas flare.

- A surface coating operation substitutes water-based inks and pigments for solvent-based inks and pigments. This reduces hazardous wastes that were formerly sent off site for incineration. Waste was generated from production activities, primarily from batch operations requiring frequent changes between different types and colors of products.

- A resins manufacturer redesigns its drumming area with separate lines for different products. This reduces the frequency of line flushing, and reduces the quantity of caustic cleaning waste.
- A batch chemicals producer upgrades its equipment to take advantage of process automation computers that virtually eliminates batch failures due to human error. As a result, fewer off-spec batches are combusted in the on-site incinerator.

Table 4: Sample New Jersey Facilities

SIC Code		Total Waste	Matched Waste		Reduction
		1993	1991	1995	
2851	Akzo Coatings, Inc., Edison	168	202	141	36.2%
2821	Cardolite Corp., Newark	197	206	189	9.2%
2869	CPS Chemical Co., Old Bridge	5,897	2,776	1,539	21.0%
2869	Elan Chemical Co., Newark	1,679	389	277	6.7%
2869	Givaudan-Roure Corp., Clifton	6,186	2,658	1,549	17.9%
2869	International Flavors & Fragrances, Union Beach	7,934	6,201	3,269	37.0%
2869	Stepan Co., Maywood	459	469	409	13.1%
	Total	24,513	14,892	9,368	25.2%

3.4 Aggregation

We combined the individual substitution demand curves in Figure 2 and Figure 3 to construct a substitution demand curve for waste minimization. This curve is shown in Figure 5.

To construct the curve, we horizontally summed the individual substitution demand curves from Figure 2 and Figure 3, then multiplied by a factor to account for the fact that many waste streams could be served by more than one technology. This factor is the sum of the tons of waste applicable to all the technologies as a group divided by the sum of the tons of waste applicable to each technology individually,[8] or 1,645,008/3,116,726 = 52.8%.[9]

A sensitivity analysis on the percent residual and the cost of residual disposal indicates that the quantity of waste minimization demanded is sensitive to changes in these variables. Four scenarios are shown in Figure 5 in addition to the Base Case. Low Cost and High Cost use 150% and 350%, respectively, as the cost of residual disposal relative to the average cost of combustion. (Base Case uses 200%.) Low Residual and High Residual use 15% and 25% residual fractions. (Base Case uses 20%.) Both the High Cost and High Residual cases lead to less waste minimization than the Base Case, while Low Cost and Low Residual both lead to more waste minimization. All five cases are significantly sensitive to changes in combustion pricing.

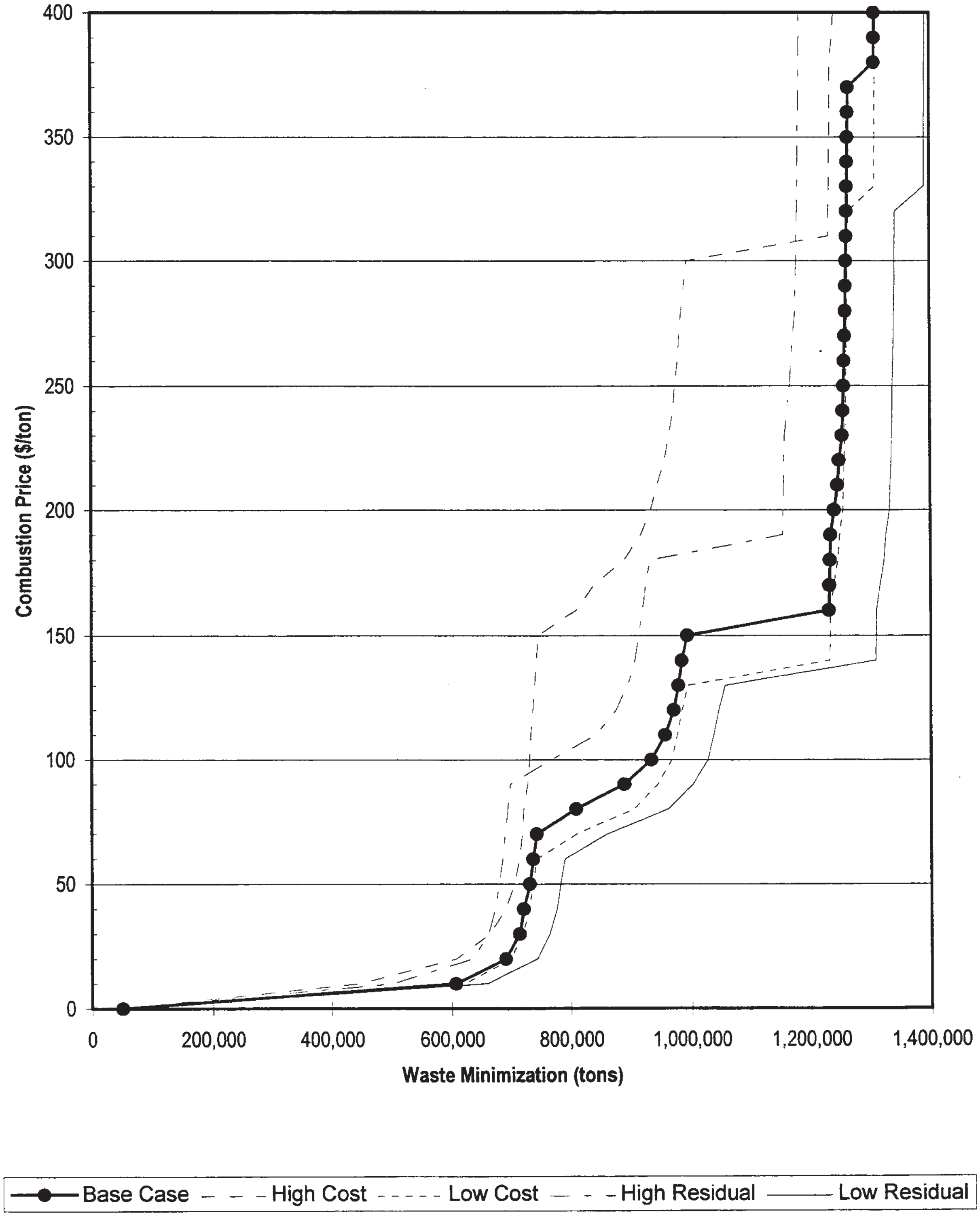
The main curve indicates that, under our assumptions, some waste minimization should already have occurred at the prevailing combustion price of approximately $70 per ton. We discuss some possible reasons for this in the next section. To reiterate an important caution for incorporating our methodology into an evaluation of the effect of EPA's proposed rule: we recommend using the curve to predict the additional waste minimization demanded if combustion prices change, rather than to predict the total quantity of waste minimization at a particular combustion price. For example, if combustion prices rise from $100 to $200 per ton, we would predict that waste minimization would increase by approximately 220,000 tons (1,420,000 - 1,200,000). Using the curve in this manner assumes that the factors that prevent achievement of the predicted level of waste minimization will continue into the future.

Table 5 recasts Figure 5 into numerical terms. If combustion rises from a starting price in the leftmost column to an ending price along the top row, the cell in the matrix at that point lists the predicted increase in waste minimization.

[8] Excluding the three technologies that were found to be not cost-effective at combustion prices less than $400.

[9] It would have been preferable to examine the technology choices of individual facilities, but the computing resources available to the project were not sufficient for this.

Figure 5: Aggregate substitution demand curve for waste minimization[10]



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[10] Excluding source reduction.

Table 5: Incremental waste minimization matrix[11]

Starting Price	Ending Price																	
	$60	$80	$100	$120	$140	$160	$180	$200	$220	$240	$260	$280	$300	$320	$340	$360	$380	$400
$60	-	72,355	196,430	233,897	247,445	493,723	495,778	502,512	510,825	517,620	519,827	521,655	523,121	524,249	525,313	526,075	570,927	571,223
$70		65,989	190,065	227,532	241,079	487,358	489,412	496,147	504,459	511,254	513,461	515,290	516,755	517,883	518,948	519,710	564,561	564,858
$80		-	124,075	161,542	175,090	421,368	423,422	430,157	438,470	445,265	447,472	449,300	450,766	451,893	452,958	453,720	498,571	498,868
$90			44,753	82,220	95,767	342,046	344,100	350,835	359,148	365,942	368,150	369,978	371,444	372,571	373,636	374,398	419,249	419,546
$100			-	37,467	51,014	297,293	299,347	306,082	314,395	321,189	323,397	325,225	326,691	327,818	328,883	329,645	374,496	374,793
$110				14,405	27,952	274,231	276,285	283,020	291,332	298,127	300,334	302,163	303,628	304,756	305,821	306,583	351,434	351,731
$120				-	13,547	259,826	261,880	268,615	276,927	283,722	285,930	287,758	289,224	290,351	291,416	292,178	337,029	337,326
$130					5,898	252,177	254,231	260,966	269,279	276,073	278,281	280,109	281,575	282,702	283,767	284,529	329,380	329,677
$140					-	246,279	248,333	255,068	263,380	270,175	272,382	274,211	275,676	276,804	277,869	278,631	323,482	323,779
$150						237,150	239,204	245,939	254,251	261,046	263,253	265,081	266,547	267,675	268,739	269,502	314,353	314,649

Values in the matrix (expressed in tons) indicate the change in waste minimization.

[11] Base Case scenario.

4. Conclusions

In the most general terms, the analysis indicates that an increase in combustion prices will make some waste minimization investments more attractive financially. So if combustion prices do indeed rise once the proposed rule is implemented, we should expect some of the waste that is currently combusted to be diverted to waste minimization. At the same time, we expect source reduction efforts—which are usually driven more by percent yield and resource efficiency improvements than by waste disposal prices—to continue to reduce the amount of hazardous waste that combustion and post-process waste minimization will manage.

In more specific terms, the substitution demand curve in Figure 5 can be used to predict the incremental quantity of waste that could be economically diverted to waste minimization if combustion prices increase. Because the curve indicates that, at the current prevailing price of combustion, some of the combusted waste streams should already have been diverted to waste minimization, we do not recommend using the curve to predict the total quantity of waste minimization at a particular combustion price.

Source reduction, which is not sensitive to changes in combustion prices, is not included in Figure 5. Including source reduction would shift the curve to the right by 508,534 tons, because at every combustion price this is the quantity of waste that would be diverted to source reduction. Source reduction also would increase the slope of the curve by 25.2%, because waste diverted to source reduction is not available for post-process waste minimization.

We did not alter the curve to show just the change in waste minimization because to do so would misrepresent the results of the analysis. There are a variety of reasons why the curve indicates that waste minimization should already have occurred, ranging from weaknesses in the data, to the many simplifying assumptions in the analysis, to regulatory, financial, and organizational barriers to waste minimization in the economy. Some of these factors point to problems in the analysis that could be rectified with better data or improved assumptions; but such improvements could change the slope and shape of the curve as easily as its position. Other factors indicate problems in the economy that prevent waste minimization from fulfilling its economic potential. This means that, for example, an increase in awareness of waste minimization options could expand actual waste minimization far beyond the marginal change between two combustion price points, as facilities begin to take advantage of opportunities that were cost-effective even before combustion prices changed. For these reasons, it is important to retain Figure 5 in its current form, while interpreting its implications carefully.

4.1 Data issues

Our underlying data, both for waste streams and technologies, are broad and lack detail. There may be significant complications, hidden by the generality of the data, that our analysis cannot account for.

- BRS does not provide enough detail to accurately characterize most combusted wastes. Information on constituents, contaminants, and concentrations are vague or absent. Some of the waste streams we deemed eligible for particular waste minimization technologies may present special circumstances that require additional investment, whether for superior equipment or for additional processing steps, that would increase the costs of waste minimization.

- Our cost information for waste minimization technologies consists of vendor quotes for basic installations. Though systematically and aggressively pursued, these price quotes are subject to wide margins of uncertainty. There may be additional equipment needed in particular cases, beyond the additional installation cost assumptions that we developed. Some waste streams may require additional processing beyond the average value of zero that we assumed for the 80% separated fraction. Neither waste stream data nor vendor information provided enough information to evaluate these possibilities.

4.2 Assumptions

In order to complete the analysis using the data and resources available, we needed to make a number of assumptions. We used best professional judgment in making these assumptions, but in using them to simplify the analysis we may have obscured important details. Some of our assumptions also may bias the analysis.

- In the waste stream analysis, we made a wide variety of assumptions to correct for flaws in BRS data. Perhaps the most important assumption was to use the quantities reported by the commercial combustion facility whenever the quantity reported by a generator exceeded the quantity reported by the combustion facility. We expect that, on average, the true quantity in such cases is actually between the two reported quantities, but closer to the combustor quantity. Thus, our waste stream analysis probably understates the total quantity of combusted waste, leading to a low estimate of waste minimization at each combustion price.

- Because equipment vendors were unable or unwilling to provide a complete cost picture, we made several assumptions in developing our cost data. Based on best engineering judgment, we estimated for each individual technology the additional installation costs that a facility might expect to incur, such as accessories, internal labor, construction permitting, etc. We also assumed that vendors underestimated the true operating costs for their technologies by 50%, by leaving out such costs as labor overhead, supervision, and the value of floor space. Most vendors provided capacity information in terms of gallons per minute, per hour, or per day. We used an average density equal to that of water and an average annual process time of 16 hours per day (2 shifts), 307 days per year (6 days per week with 6 holidays) to convert capacities to tons per year. Finally, we assumed that off-site waste management vendors would offer waste minimization services using the lowest cost installation at a price equal to twice the annualized NPC per ton. Because these assumptions are biased toward high capacity and low cost, we suspect that the net effect is to bias our cost estimates on the low side, which would lead to a high estimate of waste minimization at each combustion price.

- We used standard estimates for tax rates, the discount rate, equipment depreciation parameters, and the analysis horizon. Across the range of facilities that we analyzed, however, these parameters probably vary widely. Smaller facilities will tend to have lower tax rates, higher discount rates, and shorter time horizons than our estimates. However, we think that our estimates probably lie close to the weighted average, because larger facilities dominate the list in terms of waste volumes.

- We estimated that the various technologies produce a separated fraction of 80% and a residual of 20%. We did not attempt to develop tailored assumptions for individual technologies because the variance within technologies (i.e., for different waste streams) is probably as large as or larger than the variance between technologies. We used an average economic value of zero for the separated fraction, and an average combustion cost for the residual equal to twice the combustion price. The true values probably vary widely, and we cannot predict the net effect these assumptions have on the analysis. Sensitivity analysis on the residual fraction and its cost of combustion relative to the prevailing combustion price showed that the change in waste minimization is sensitive to these variables.

- The concept of an average price for hazardous waste combustion is a necessary simplification, but in the combustion market some wastes will cost significantly more or less than average to combust. Also we did not account for facilities with on-site combustion facilities, for whom the cost of combustion under the proposed rule may change more dramatically than in the commercial combustion market. The effects of these omissions on the analysis are difficult to predict.

- Accounting for the comparable fuels exemption, under which certain wastes can be combusted at very low—or even negative—cost, would reduce the quantity of waste minimization predicted by the analysis.

- In summing the individual substitution demand curves to produce an aggregate curve, we factored out waste streams that can be served by more than one technology using the average overlap, as detailed in Section 3.4. According to our assumptions, facilities should select the lowest cost technology, so this method of factoring out overlap biases the curve toward a low estimate of waste minimization at each combustion price. However, the assumption that facilities will select the lowest cost technology is probably wrong on average, because there are other considerations that enter into the technology choice decision, such as waste stream composition and facility site characteristics.

- In estimating future source reduction potential, we relied on several assumptions: (1) that the sample facilities were particularly proactive with regard to source reduction, both because of the source reduction incentives inherent in New Jersey law and because they had demonstrated significant source reduction achievements; (2) that source reduction achievements with regard to TRI chemicals can be translated into reductions in matched BRS wastes; (3) that the sample facilities reasonably represent all chemical facilities in terms of the quantity of source reduction opportunities; and (4) that other, less proactive facilities will become more proactive in the future. Based on these assumptions, source reduction progress from 1991 to 1995 at a representative sample of facilities on the cutting edge of pollution prevention is a good indicator of the minimum source reduction we should expect over the next decade from all facilities. The second assumption is the most tenuous, but we know of no better way to broadly estimate source reduction potential for BRS wastes. We attempted to analyze a larger sample of facilities to strengthen the third assumption, but were unable to do so given the available data and the parameters of the project. In terms of the true potential for economically favorable source reduction, our estimate represents a minimum, because it is based on source reduction that has already been achieved. But because many facilities will probably fail to exploit all of the opportunities available to them, the actual quantity of source reduction achieved may be lower than the potential.

In addition to the effects of these various assumptions, there are time inconsistencies inherent in the substitution demand curve's construction. Though the curve ostensibly represents the future, the cost data on which the financial analyses are based are current as of 1997, and the waste stream data are from 1993. The estimate of source reduction is geared toward the future based on the assumptions listed above, but we could not specify the precise future period or duration to which the estimate applies. The proposed rule will not go into effect before 1998, and combustion facilities will not be required to comply until three years later. Thus, the full extent of any increase in combustion prices will not be realized until at least 2001. In the intervening years, waste minimization technologies will probably become more competitive, providing better services at lower price points, and new technologies may be developed. Similarly, the volume and composition of combusted waste streams will change, probably toward smaller volumes with smaller fractions of chlorinated organics, but with higher concentrations of other contaminants.

4.3 Barriers to waste minimization

Though there are a number of factors intrinsic to the analysis and the data on which it is based, perhaps the most important reasons that facilities have not invested in waste minimization opportunities that appear to be economically feasible are a mix of regulatory, financing, and organizational barriers.

Many firms have demonstrated the cost-effectiveness of waste minimization opportunities in the form of input substitution, process and product redesign, and recycling. Nonetheless, many opportunities remain untapped despite favorable economics, a phenomenon observed by EPA itself in its Environmental Accounting Project research. This reality, of course, has direct consequences for estimating the diversion rates of combusted wastes once a new MACT rule is in place. It means that higher prices created by a new MACT standard for combustors will not automatically translate into additional source reduction investments. Whatever the reason—technological inertia, faulty accounting systems, regulatory impediments, capital shortages—the result is less source reduction investment than one would anticipate on the basis of economics alone.

Taking a closer look at some of the reasons a firm may not pursue cost-effective source reduction projects, the following are candidates:

- Biased accounting systems

  Few firms have modified their accounting systems to incorporate the difficult to quantify and less tangible costs that are often important in justifying waste minimization investments. Many firms fail to allocate common overhead costs—such as waste disposal fees, environmental staff labor, and purchasing overhead—to the processes and products that cause them. Smaller firms often use time horizons of five years or less, and most use simple payback as the sole indicator of project profitability. Even large firms often use return on investment (ROI), which does not account for the time value of money, as a profitability indicator. These practices lead to faulty financial analysis of investment projects and a bias against waste minimization.

Only a small minority of firms have materials accounting systems that track the flow of chemicals through their facilities. Even fewer attach costs to these flows. Without materials accounting, facilities have difficulty identifying waste minimization opportunities; without materials cost accounting, facilities may have difficulty justifying waste minimization investments.

- Capital scarcity

  Capital—like labor, technology, and materials—is a scarce resource. Even large, well-capitalized firms do not have access to unlimited capital from internal or external sources. Waste minimization projects compete not only with other capital projects but also with altogether different uses of capital such as research and development, marketing, and debt retirement. Debt financing may be an option, but accruing debt liability affects the balance sheet which, in turn, affects credit ratings and shareholder value. Thus, an attractive rate of return is a necessary, but not sufficient condition to ensure support for a worthy waste minimization project.

- Competition from market expansion and new product development projects

  Managers routinely make choices of where to invest limited capital. In general, projects which (a) increase capacity to serve growing markets for existing products or (b) create production capacity for new product lines receive priority over projects labeled "environmental." Even when the latter are couched as resource efficiency improvements (as in the case of source reduction), market expansion and new product development normally are favored by managers as the foremost contributors to the firm's profitability and overall economic performance. This was recently demonstrated in the case of Dow Chemical's La Porte, Texas, facility. The LaPorte facility manufactures methylene diamine diisocyanate (MDI), a major ingredient in foamed and thermoplastic polyurethane. An assessment of pollution prevention projects yielded returns on investment of as high as 70%, yet management has postponed investments because of competition from more promising business opportunities with, in the opinion of management, greater strategic value.

- Incompatibility with business strategy

  Downsizing, consolidation, and acquisitions and mergers continue to reshape the American industrial landscape. A worthy waste minimization project in a plant slated for partial or complete closing certainly will be bypassed in favor of investment in facilities with longer life expectancies. Of course, in the long run, the environmental benefits of new plant and equipment which embody high efficiency, resource-conserving production technologies will contribute to pollution reduction. But in the short term, the uncertainties surrounding the future configuration of a firm's manufacturing system may stall or cancel proposed waste minimization projects.

- Regulatory obstacles

  This barrier to waste minimization comes in a variety of forms. In the pharmaceutical industry, where both products and processes are highly regulated by the Food and Drug Administration, any change to less hazardous or recycled materials in manufacturing requires a long approval process. This time requirement itself may dissuade a facility from initiating such a process modification to yield waste minimization. In the defense industry, also subject to tight certification standards for materials used in manufacturing weapons components, military specifications often impose rigid requirements that discourage adoption of cleaner production methods and the use of less hazardous or recycled materials. On a more general level, technology-based standards may capture "best practices" at a particular point in time, but often inhibit innovation if, as is often the case, waste minimization is not explicitly written into the regulation as an alternative to the prescribed technology options. Finally, quantity-based standards without economic incentives (such as pollution fees or tradable permits) provide little incentive to surpass—rather than just satisfy—regulatory goals.

In short, unless they demonstrate profitability, waste minimization projects which go beyond compliance will not secure management approval. But even profitability is not enough. Though high combustion prices will improve the economics of waste minimization, waste generating firms will continue to weigh worthy waste minimization projects against alternative uses of capital. Aggregating these decisions across large numbers of firms in the sectors we have targeted injects an additional element of uncertainty in our estimates of diverted waste.

4.4 Recommendation

Intuition suggests, and our analysis confirms, that if combustion prices rise upon implementation of the proposed rule, waste minimization will become more attractive as an alternative. Waste minimization offers the potential to reduce the quantity of hazardous waste that is combusted, provide competition that can dampen combustion price increases, and reduce the costs of compliance for combustion vendors and on-site incinerators.

We recommend that EPA use the substitution demand curve and estimate of source reduction potential developed in this analysis to examine the potential effects of waste minimization on the hazardous waste combustion market. Waste minimization's first order effect will be to reduce the quantity of waste combusted, but it is also important to take into account the feedback loop between the reduced quantity of combusted waste and the price of combustion. Including waste minimization in its analysis will help EPA avoid overestimating the total cost of compliance.

5. BRS Data Issues

5.1 BRS data format

The BRS data used in this analysis are based on two types of forms submitted by hazardous waste generators and combustors.

- Form GM (Waste Generation and Management) is submitted by all Large Quantity Generators (LQGs). Form GM contains data for each hazardous waste stream generated at an individual facility. On Form GM, a waste stream is defined as a unique combination of Standard Industrial Classification (SIC) code,[12] source code (the waste generating process), form code (the physical nature of the waste), system code (the method of waste management), and destination facility (or on-site management). Each waste stream of Form GM is represented in the databases as an individual record. Facilities may report waste stream magnitude in a variety of units; for this analysis we converted all submissions to tons using EPA's calculation methodology, which assigns a specific gravity of 1.00 to any reported specific gravity outside the plausible range of 0.40–15.00.

- Form WR (Waste Received from Off Site) is submitted by facilities that receive hazardous wastes from off site—primarily waste management vendors. Form WR contains data for each hazardous waste stream received by a facility. For this purpose, a waste stream is defined as a unique combination of facility of origin (reported on Form WR as an EPA ID number), form code, and system code. The source code and SIC code from the facility of origin are not reported on Form WR. As with Form GM, we converted all submissions to tons.

5.2 Databases used in the analysis

For this analysis, we selected a subset of BRS data. The data are contained in several database tables specific to this analysis.

- ONSITE is drawn from Form GM submissions by facilities with on-site incinerators. Although most of these facilities are not combustion vendors, wastes generated and combusted on site by combustion vendors are also included. Specifically, ONSITE includes Form GM wastes managed on site with system codes M041 through M049. ONSITE's fields are source ID, SIC code, source code, form code, system code, and tons.

- OFFSITE-WR is drawn from Form WR submissions by combustion vendors, including commercial incinerators, cement kilns, and lightweight aggregate kilns (LWAKs). Specifically, OFFSITE-WR includes Form WR wastes with system codes

[12] "SIC codes" in this memo are at the 4 digit level.

M041 through M059. OFFSITE-WR's fields are destination ID, source ID, form code, system code, and tons.

- OFFSITE-GM is drawn from Form GM submissions by Large Quantity Generators (LQGs) that sent hazardous wastes to combustion vendors (i.e., system codes M041–61). OFFSITE-GM's fields are source ID, destination ID, SIC code, source code, form code, system code, and tons.

- FUELBLEND-WR is drawn from Form WR submissions by facilities that blend hazardous wastes with virgin fuels for combustion. Some fuel blenders are vertically integrated with kilns or incinerators, but others are middlemen who forward the wastes, variously, to kilns, commercial incinerators, and other waste management vendors. Specifically, FUELBLEND-WR contains Form WR wastes with system code M061.

5.3 Inherent limitations of BRS data

- Only Form GM contains SIC code and source code information, but Small Quantity Generators (SQGs) do not submit Form GM. The only record of combusted SQG wastes is in Form WR submissions, each of which contains the EPA ID number of the facility of origin, but no SIC code or source code.

    - Using a database that matches selected source IDs to SIC codes from EPA's FINDS database, we were able to identify appropriate SIC codes for many SQGs.

    - We also were able in some cases to infer the correct source code from the form code. Twelve form codes were matched, among complete records, to a particular source code with greater than 75% frequency. We used these twelve form code/source code pairs to update some of the records lacking source codes. The pairs are shown on Table 6.

Table 6: Common form/source combinations

Form Code	Source Code
B107	A22
B109	A37
B113	A37
B115	A78
B116	A79
B307	A40
B502	A75
B503	A75
B504	A75
B514	A69
B608	A60
B701	A89

- System codes M051–59 (energy recovery) include, but do not distinguish among, cement kilns, LWAKs, on-site BIFs, and incinerators that have energy recovery systems. Thus, ONSITE excludes wastes combusted in on-site incinerators but reported with system codes M051–59. Such wastes, unfortunately, are indistinguishable from wastes burned in on-site BIFs. We and IEc elected to exclude these wastes rather than run the risk of overstating relevant wastes by mistakenly including wastes burned in on-site BIFs.

5.4 BRS data errors

5.4.1 Missing or invalid data

- Many records in ONSITE lack SIC codes, source codes, or form codes. Nineteen percent of the total tonnage is in records lacking at least one of these codes.
- Many records in OFFSITE-GM lack form codes, accounting for twenty five percent of the total tonnage.
- Facilities in Ohio, Tennessee, and Texas report to their respective states using special state-specific forms. When these states forward data to EPA, it is often without valid source codes, SIC codes, or form codes.
    - The Environmental Affairs Department of Tennessee Eastman-Kingsport, a facility responsible for 62% of the tonnage in ONSITE incomplete records, provided 1995 data for all on-site combusted hazardous wastes at the facility over 93 tons. We used these data in place of 1993 data for wastes over 93 tons. We also preserved the 1993 data for wastes at the facility under 93 tons. Where Tennessee Eastman listed two SIC codes for a single waste, we assigned 50% of the waste to each SIC code.
    - Many facilities in Texas reported special Texas form codes. Texas's form codes are a superset of EPA's codes. With assistance from DuPont–La Porte and the Texas Natural Resource Conservation commission, we converted the

extra Texas form codes into EPA format, according to Table 7. Some Texas form codes are for nonhazardous waste (Texas Class 1 wastes), and should

Table 7: Texas form codes

Texas	EPA
B198	none
B199	B113
B296	B219
B297	B206
B298	B206
B299	none
B393	B315
B398	B301
B399	B301
B488	none
B489	none
B490	none
B491	B607
B492	B608
B493	B405
B494	B407
B495	B407
B498	B407
B499	B407
B597	B509
B695	none
B696	none
B697	B605
B901	none
B902	none

not have been reported to BRS. We deleted these records.

- Many facilities reported invalid SIC codes, source codes, and form codes. In some cases, we were able to identify the proper code (for example; source code 49 became A49; form code 8201 became B201). We deleted invalid codes from the remaining records.

5.4.2 Combustion facilities

Using EPA lists of facilities permitted for hazardous waste combustion as of November 1, 1994, we identified the plausible universe of incinerators, cement kilns, LWAKs, commercial boilers, and on-site boilers and industrial furnaces (BIFs). We assumed that all other facilities not appearing on these lists, but reporting receipt of hazardous waste under system codes M041-61, were fuel blenders.

- We removed records of waste combusted in on-site BIFs from consideration, because on-site BIFs are not subject to the proposed MACT rule.

- We also removed waste originating at off-site combustion facilities, under the assumption that such facilities primarily handle wastes generated off site.

- We elected to reclassify wastes combusted by Marine Shale Processors, a LWAK that combusted hazardous waste in 1993 but is now barred from doing so, as incinerated wastes. Marine Shale Processors tended to combust wastes with high contaminant and solids content, so these wastes now are most likely combusted by incinerators.

6. Analysis Methodology

The object of this task was to identify and characterize candidate waste streams. A waste stream is defined as a unique combination of SIC code, source code, and form code. The steps constituting the analysis are as follows.

6.1 Data modifications to account for fuel blenders

- Fuel blending facilities submit Form GM in addition to Form WR. Thus a simple query of OFFSITE-GM will double count some wastes that were first generated at LQG facilities, then blended at fuel blending facilities. To avoid such double counting, we removed fuel blending facilities (those reporting receipt of waste on Form WR under system codes M041-61, but not listed among facilities permitted to combust waste) to a separate database, FUELBLEND-GM.

- In addition, we removed all records from facilities with SIC code 4953, "Refuse systems," as well as records from 23 other selected facilities (Safety-Kleen, Chemical Resource Processors, Waste Recovery Services, Capital Parts Washers, and Enviroserve, all with SIC code 7389, "Business services, not elsewhere classified,") under the assumption that such facilities primarily handle wastes originally generated off site.

- Fuel blending facilities send some wastes to combustors and other wastes to vendors offering alternative waste management methods. Using the source IDs in FUELBLEND-GM, we obtained Form GM and Form WR submissions from these facilities with system codes other than M041-61. By assuming that fuel blending facilities do not add virgin fuels to wastes destined for management systems other than combustion, we were able to calculate the portion of the wastes received by fuel blenders sent to combustion. The formula is $P = 1 - A/B$, where A is the sum of fuel blender Form GM submissions with system codes other than M041-61, and B is the sum of all fuel blender Form WR submissions, including both FUELBLEND-WR and the additional Form WR submissions with system codes other than M041-61. $P = 0.543$. Using the simplifying assumption that fuel blenders divide all wastes among combustion and non-combustion alternatives according to the proportion P, we estimated the portion of each waste stream sent to fuel blenders that is eventually combusted. Although this assumption clearly has its limitations, we judged that the distortion of the data is probably less than if all fuel blender waste were assumed to be combusted, and that developing stronger assumptions about these wastes would involve an effort disproportionate to the likely analytical improvement.

6.2 Waste stream consolidation and aggregation

We first consolidated waste stream data from the various databases into one table of facility waste streams, which are unique combinations of generator ID, SIC code, source code, form code, system type, and destination ID. System type distinguishes on-site incinerators, commercial incinerators, fuel blenders, cement kilns, LWAKs, and commercial boilers, based on the destination ID. This new table contained the following records:

- ONSITE
- OFFSITE-GM (from which, as noted above, fuel blender Form GM submissions had been removed), system types other than fuel blending
- *P** OFFSITE-GM, system type fuel blending
- OFFSITE-WR, but not including wastes from LQGs and fuel blenders; these records represent wastes from SQGs sent directly to combustors
- *P** FUELBLEND-WR, but not including wastes from LQGs; these records represent wastes from SQGs sent to fuel blenders

P is the portion of waste sent to fuel blenders that is eventually combusted.

For the SQGs, we included SIC code data from EPA's FINDS database. For SQGs with more than one SIC code, we divided the wastes evenly among SIC codes.

We then aggregated the facility waste streams into waste streams, defined by unique combinations of SIC code, source code, and form code.

6.3 Reconciliation of Form GM submissions to Form WR submissions

As a whole, generating facilities reported sending 8,244,000 tons of hazardous waste to combustion facilities (including fuel blenders) on Form GM, while combustion facilities reported receiving only 3,765,000 tons on Form WR. We concluded that most of the discrepancy is probably the result of both reporting errors on the part of generators and data entry errors or quality control oversights on the part of EPA.[13] Accordingly, we reconciled the Form GM and Form WR records as follows.

- For every generating facility that reported sending more waste to a particular combustion facility than the combustion facility reported receiving from that generator, we reduced the volume to the level reported by the combustion facility, under the assumption that the generating facility reported incorrectly. If multiple facility waste streams (combinations of SIC code, source code, form code, and system code) were involved, we reduced each proportionately. (Due to the lack of SIC codes and source

[13] For example, one facility that we contacted directly explained that two waste streams reported as sent to an off-site incinerator were actually deep-well injected on site. Upon reviewing its BRS reporting forms from 1993, the facility found that it had reported these two waste streams correctly as deep-well injected on site, and that EPA had erred when keying in the data. These two waste streams totaled over 1.7 million tons, and represented more than 30% of the discrepancy between Form GM combusted wastes and Form WR combusted wastes. Several other facilities accounted for most of the rest of the discrepancy.

codes on Form WR, and the subjective nature of form codes, it is not possible to match Form GM and Form WR wastes at the facility waste stream level.)

- If a facility permitted to combust hazardous waste or a facility listed in FUELBLEND-WR as a fuel blender did not report receiving waste from a generating facility that reported sending waste to it, we assumed that the waste was not combusted, and deleted the record.

- We did not revise records of waste sent to other facilities (i.e. fuel blenders not listed in FUELBLEND-WR) because, due to shortage of time, Form WR submissions from these facilities were not available to the analysis.

- We did not revise records of waste combusted on site.

Even after these adjustments, the total volume of combusted hazardous waste analyzed (3,159,000 tons) still differed from the volume of hazardous waste reported received by combustion facilities on Form WR (3,765,000 tons), for two reasons: (1) some generating facilities reported sending less waste to combustion facilities than combustion facilities reported receiving from them—we did not increase these volumes; and (2) we were not able to reconcile wastes sent to fuel blenders not listed in FUELBLEND-WR.

6.4 Waste stream characterization

We characterized each waste stream according to three parameters: volume, number of generating facilities, and combustor profile.

- Volume is the sum in tons of all individual facility waste streams that make up a waste stream.

- The number of generators is calculated by counting the unique EPA ID numbers among the records that make up a waste stream, so that facilities that submit multiple records of similar wastes are counted only once.

- The combustor profile is the apportionment of the waste stream among the five combustor types: on-site incinerators, commercial incinerators, cement kilns, LWAKs, and commercial boilers; as well as the portion that is channeled to combustors by fuel blenders. We assumed that wastes sent to fuel blenders were evenly mixed, and assigned a combustor profile to each fuel blended waste equal to the average combustor profile of all fuel blended wastes. The average combustion profile of fuel blended wastes is 59.63% cement kiln, 34.03% incinerator, 2.91% on site (i.e., incinerators classified as on-site but receiving waste from off site), 2.81% LWAK, and .07% commercial boiler.

APPENDIX B: SAMPLE FINANCIAL ANALYSIS

7. Data Inputs

The data inputs are described in Table 8.

Table 8: Data inputs to the financial analysis

Global Inputs		Value
Discount rate	Real rate at which future cash flows are discounted in calculating NPV	12%
Tax rate	Rate at which profits (after expenses and depreciation are deducted) are taxed	36%
Analysis horizon	Horizon for calculating NPV; also equal to the useful lifetime of equipment	15 years
Depreciation type	Method for depreciating capital expenses, using the half year convention	DDB
Depreciation period	Period for depreciating capital equipment, based on IRS equipment categories	7 years
Residual	Portion of waste that remains after processing	20%
Residual cost	Unit cost—relative to the combustion price—to dispose of residual	200%
Technology-specific Inputs		
Off site	Is the technology amenable to off-site installation?	
Eligible wastes	SIC codes, source codes, and form codes of wastes eligible for processing	
Operating cost	Average vendor estimate of operating and maintenance costs, plus 50%	
Capital scale-specific inputs		
Capacity	Quantity of waste in tons per year that can be processed Calculated from gallons per unit time using the density of water, 16 hours per day (two shifts), and 307 days per year (six day weeks with five holidays)	
Capital cost	Vendor price for capital equipment	
Installation cost	Additional costs (as a percent of to capital cost) associated with installation	

8. Analysis Structure

For each technology, we analyzed every eligible waste stream at every individual facility. For each waste stream, the facility needs to decide whether to invest in the technology, utilize off-site technology services, or continue to combust the waste. To model this decision, we first selected the appropriate capital scale, then calculated the after-tax expenditures associated with on-site technology (except for the cost to combust the residual) over the analysis horizon. This is demonstrated in Table 9.

Table 9: Costs incurred in each analysis year

Year	Costs Incurred	Cost Equation
0	Capital and installation costs	Capital + Installation * Capital
1	Operating costs (tax deductible), tax deduction for the entire installation cost, tax deduction for ½ year of capital depreciation	(1 - Tax) * Operating * Quantity - Tax * Installation - Tax * Depreciation[1]
2–7	Operating costs (tax deductible), tax deduction for 1 year of capital depreciation	(1 - Tax) * Operating * Quantity - Tax * Depreciation
8	Operating costs (tax deductible), tax deduction for ½ year of capital depreciation	(1 - Tax) * Operating * Quantity - Tax * Depreciation
9–15	Operating costs (tax deductible)	(1 - Tax) * Operating * Quantity

1. Double declining balance (over straight line) depreciation is calculated according to the half year convention.

We then calculated the after-tax NPV, which is

$$NPV = \sum_0^{Horizon} \frac{-Cost}{(1 + Discount)^{year}}.$$

We calculated the equivalent negative fifteen year constant cash flow (annualized NPC), which we then compared to the price of off-site services for the technologies amenable to off site installation. We estimated the price of off-site services by doubling the lowest annualized NPC at any individual facility.

To compare the lower of these two prices to the price of combustion, we needed to allow for both tax deductions and the cost to combust the residual. Accordingly, we compared the annualized NPC to the quantity

$$(1 - Tax) * CombustPrice * (1 - ResidualCost * Residual).$$

If the annualized NPC was less than this quantity, we assumed that 80% $(1 - Residual)$ of the facility's waste stream would be diverted from combustion.

For each waste stream at each facility, we conducted this comparison for combustion prices between $50 and $400 per ton, in $10 increments. The sum of all the wastes diverted to the technology at a particular price provided a point on the substitution demand curve.

9. Sample Analysis

Figure 6 presents a sample analysis for a waste stream at an individual facility. Grid 1 displays values for the data inputs listed in Table 8. Grid 2 shows the costs incurred in each year up to the fifteen year horizon in three categories: capital, installation, and operating. In year zero, which represents the initial installation period, the facility incurs $50,000 in capital costs and $15,000 (30% * $50,000) in installation costs. In year 1, the facility begins to operate the equipment, incurring $502.46 (130.95 tons * $3.837/ton) in operating costs. However, operating costs are tax deductible, so the facility's tax bill decreases by $180.89 (36% * $502.46), for a net cost of $321.58. The facility also can expense the installation costs in year 1, reaping a tax windfall of $5,400 (36% * $15,000). Finally, the initial capital investment is depreciated according to IRS guidelines, which categorize most industrial equipment as depreciable over seven years using a double declining balance and the half year convention. This means that the facility can deduct only the first half year of depreciation in year 1, or $7,142.86. This provides a tax benefit of $2,571.43 (36% * $7,142.86). The sum of these costs and benefits is a net gain of $7,650 for year 1. But at a discount rate of 12%, this is worth just $6,732 in year zero terms.

The sum of the discounted cash flows over all fifteen years is a $50,549.36 net expense, as shown in Grid 3. This is equivalent to spending $7,421.87 every year for fifteen years—the annualized NPC. Dividing by 130.95 tons yields a per ton cost of $56.68.

To compare this figure to combustion prices, we accounted for both taxes and the cost to combust the residual 20% left over after waste minimization. For example, if the price of combustion is $100 per ton, the after tax price is $64 ((100% - 36%) * $100), while the residual (.2 tons per ton processed) will cost $40 to combust (20% * 200% * $100), or $25.60 ((100% - 36%) * $40) after tax. Thus the effective cost of waste minimization is $82.28 ($56.68 + $25.60) per ton, while combustion effectively costs $64 per ton. Thus, if the price of combustion is $100 per ton, the facility will decide to combust its waste. Note that if the price of combustion rises to $200 per ton, the facility will invest in waste minimization.

Figure 6: Sample financial analysis

1. Data Inputs	
Tons	130.95
Capital	$ 50,000
Installation	30%
Operating	$ 3.837
Discount	12%
Tax	36%
Horizon	15
Residual	20%
ResidualCost	200%
OffSite	FALSE

2. Annual Costs					
Year	Capital	Installation	Operating	Total	Discounted
0	$ 50,000.00	$ 15,000.00	$ -	$ 65,000	$ 65,000
1	$ (2,571.43)	$ (5,400.00)	$ 321.58	$ (7,650)	$ (6,830)
2	$ (4,408.16)	$ -	$ 321.58	$ (4,087)	$ (3,258)
3	$ (3,148.69)	$ -	$ 321.58	$ (2,827)	$ (2,012)
4	$ (2,249.06)	$ -	$ 321.58	$ (1,927)	$ (1,225)
5	$ (1,606.47)	$ -	$ 321.58	$ (1,285)	$ (729)
6	$ (1,606.47)	$ -	$ 321.58	$ (1,285)	$ (651)
7	$ (1,606.47)	$ -	$ 321.58	$ (1,285)	$ (581)
8	$ (803.24)	$ -	$ 321.58	$ (482)	$ (195)
9	$ -	$ -	$ 321.58	$ 322	$ 116
10	$ -	$ -	$ 321.58	$ 322	$ 104
11	$ -	$ -	$ 321.58	$ 322	$ 92
12	$ -	$ -	$ 321.58	$ 322	$ 83
13	$ -	$ -	$ 321.58	$ 322	$ 74
14	$ -	$ -	$ 321.58	$ 322	$ 66
15	$ -	$ -	$ 321.58	$ 322	$ 59

3. Data Outputs	
NPV	$ (50,111.66)
Annualized NPC	$7,357.61
AnnNPC/Ton	$ 56.18

4. Waste Minimization v. Combustion					
Combustion Price	$ 50.00	$ 100.00	$ 200.00	$ 300.00	$ 400.00
After Tax	**$ 32.00**	**$ 64.00**	**$ 128.00**	**$ 192.00**	**$ 256.00**
Waste Min Price	$ 56.18	$ 56.18	$ 56.18	$ 56.18	$ 56.18
Residual After Tax	$ 12.80	$ 25.60	$ 51.20	$ 76.80	$ 102.40
Total Waste Min	**$ 68.98**	**$ 81.78**	**$ 107.38**	**$ 132.98**	**$ 158.58**
Decision	Combust	Combust	Waste Min	Waste Min	Waste Min
Tons Diverted	**0**	**0**	**104.76**	**104.76**	**104.76**

APPENDIX C: SIC CODES, SOURCE CODES, AND FORM CODES

10. SELECTED SIC CODES

SIC Code	Description
1611	Highway & street construction
1622	Bridge, tunnel, & elevated highway
1623	Water, sewer, & utility lines
2087	Flavoring extracts & syrups, NEC
2652	Setup paperboard boxes
2812	Alkalies & chlorine
2813	Industrial gases
2816	Inorganic pigments
2819	Industrial inorganic chemicals, NEC
2821	Plastics materials & resins
2822	Synthetic rubber
2823	Cellulosic manmade fibers
2824	Organic fibers, noncellulosic
2833	Medicinals & botanicals
2834	Pharmaceutical preparations
2835	Diagnostic substances
2836	Biological products exc. diagnostic
2841	Soap & other detergents
2842	Polishes & sanitation goods
2843	Surface active agents
2844	Toilet preparations
2851	Paints & allied products
2861	Gum & wood chemicals
2865	Cyclic crudes & intermediates
2869	Industrial organic chemicals, NEC
2873	Nitrogenous fertilizers
2874	Phosphatic fertilizers
2875	Fertilizers, mixing only
2879	Agricultural chemicals, NEC
2891	Adhesives & sealants
2892	Explosives
2893	Printing ink
2895	Carbon black
2899	Chemical preparations, NEC
2911	Petroleum refining
3321	Gray & ductile iron foundries
3354	Aluminum extruded products
3355	Aluminum rolling & drawing, NEC
3441	Fabricated structural metal
3443	Fabricated plate work (boiler shops)
3452	Bolts, nuts, rivets, & washers
3471	Plating & polishing
3479	Metal coating & allied services
3499	Fabricated metal products, NEC
3585	Refrigeration & heating equipment
3612	Transformers, except electronic
3672	Printed circuit boards
3674	Semiconductors & related devices

3714	Motor vehicle parts & accessories
3721	Aircraft
3724	Aircraft engines & engine parts
3743	Railroad equipment
3764	Space propulsion units & parts
3823	Process control instruments
3861	Photographic equipment & supplies
4011	Railroads, line-haul operating
4111	Local and suburban transit
4225	General warehousing & storage
4226	Special warehousing & storage, NEC
4231	Trucking terminal facilities
4922	Natural gas transmission
5043	Wholesale photographic equipment & supplies
5171	Petroleum bulk stations & terminals
5541	Gasoline service stations
7699	Repair services, NEC
7996	Amusement parks
8062	General medical & surgical hospitals

11. SOURCE CODES

Source Code	Description
A01	Stripping
A02	Acid cleaning
A03	Caustic cleaning
A04	Flush rinsing
A05	Dip rinsing
A06	Spray rinsing
A07	Vapor degreasing
A08	Physical scraping and removal
A09	Clean out process equipment
A19	Other cleaning and degreasing
A21	Painting
A22	Electroplating
A23	Electroless plating
A24	Phosphating
A25	Heat treating
A26	Pickling
A27	Etching
A29	Other surface coating/preparation (specify)
A31	Product rinsing
A32	Product filtering
A33	Product distillation
A34	Product solvent extraction
A35	By-product processing
A36	Spent catalyst removal
A37	Spent process liquids removal
A38	Tank sludge removal
A39	Slag removal
A40	Metal forming
A41	Plastics forming
A49	Other processes other than surface preparation (specify)
A51	Leak collection

A53	Cleanup of spill residues
A54	Oil changes
A55	Filter/Battery replacement
A56	Discontinue use of process equipment
A57	Discarding off-spec material
A58	Discarding out-of-date products or chemicals
A59	Other production-derived one-time and intermittent
A60	Sludge removal
A61	Superfund Remedial Action
A62	Superfund Emergency Response
A63	RCRA Corrective Action at solid waste management unit
A64	RCRA closure of hazardous waste management unit
A65	Underground storage tank cleanup
A69	Other remediation
A71	Filtering/screening
A72	Metals recovery
A73	Solvents recovery
A74	Incineration/thermal treatment
A75	Wastewater treatment
A76	Sludge dewatering
A77	Stabilization
A78	Air pollution control devices
A79	Leachate collection
A89	Other pollution control or waste treatment
A91	Clothing and personal protective equipment
A92	Routine cleanup wastes
A93	Other closure of management unit or equipment
A94	Laboratory wastes
A99	Other

12. FORM CODES

Form Code	Description
B001	Lab packs of old chemicals only
B002	Lab packs of debris only
B003	Mixed lab packs
B004	Lab packs containing acute hazardous wastes
B009	Other lab packs (specify)
B101	Aqueous waste with low solvents
B102	Aqueous waste with low other toxic organics
B103	Spent acid with metals
B104	Spent acid without metals
B105	Acidic aqueous waste
B106	Caustic solution with metals but no cyanides
B107	Caustic solution with metals and cyanides
B108	Caustic solution with cyanides but no metals
B109	Spent caustic
B110	Caustic aqueous waste
B111	Aqueous waste with reactive sulfides
B112	Aqueous waste with other reactives
B113	Other aqueous waste with high dissolved solids
B114	Other aqueous waste with low dissolved solids
B115	Scrubber water

B116	Leachate
B117	Waste liquid mercury
B119	Other inorganic liquids (specify)
B201	Concentrated solvent-water solution
B202	Halogenated solvent
B203	Nonhalogenated solvent
B204	Halogenated/nonhalogenated solvent mixture
B205	Oil-water emulsion or mixture
B206	Waste oil
B207	Concentrated aqueous solution of other organics
B208	Concentrated phenolics
B209	Organic paint, ink, lacquer, or varnish
B210	Adhesives or epoxies
B211	Paint thinner or petroleum distillates
B212	Reactive or polymerizable organic liquid
B219	Other organic liquids (specify)
B301	Soil contaminated with organics
B302	Soil contaminated with inorganics only
B303	Ash, slag, or other residue from incineration of wastes
B304	Other "dry" ash, slag, or thermal residue
B305	"Dry" lime or metal hydroxide solids chemically "fixed"
B306	"Dry" lime or metal hydroxide solids not "fixed"
B307	Metal scale, filings, or scrap
B308	Empty or crushed metal drums or containers
B309	Batteries or battery parts, casings, cores
B310	Spent solid filters or adsorbents
B311	Asbestos solids and debris
B312	Metal cyanide salts/chemicals
B313	Reactive cyanide salts/chemicals
B314	Reactive sulfide salts/chemicals
B315	Other reactive salts/chemicals
B316	Other metal salts/chemicals
B319	Other waste inorganic solids (specify)
B401	Halogenated pesticide solid
B402	Nonhalogenated pesticide solid
B403	Solid resins or polymerized organics
B404	Spent carbon
B405	Reactive organic solid
B406	Empty fiber or plastic containers
B407	Other halogenated organic solids (specify)
B409	Other nonhalogenated organic solids (specify)
B501	Lime sludge without metals
B502	Lime sludge with metals/metal hydroxide sludge
B503	Wastewater treatment sludge with toxic organics
B504	Other wastewater treatment sludge
B505	Untreated plating sludge without cyanides
B506	Untreated plating sludge with cyanides
B507	Other sludge with cyanides
B508	Sludge with reactive sulfides
B509	Sludge with other reactives

B510	Degreasing sludge with metal scale or filings
B511	Air pollution control device sludge
B512	Sediment or lagoon dragout contaminated with organics
B513	Sediment or lagoon dragout contaminated with inorganics only
B514	Drilling mud
B515	Asbestos slurry or sludge
B516	Chloride or other brine sludge
B519	Other inorganic sludges (specify)
B601	Still bottoms of halogenated solvents or other organic liquids
B602	Still bottoms of nonhalogenated solvents or other organic liquids
B603	Oily sludge
B604	Organic paint or ink sludge
B605	Reactive or polymerizable organics
B606	Resins, tars, or tarry sludge
B607	Biological treatment sludge
B608	Sewage or other untreated biological waste
B609	Other organic sludges (specify)
B701	Inorganic gases
B801	Organic gases